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# THESIS

**ASSESSING AND RANKING MULTI-ATTRIBUTE DECISION ALTERNATIVES: AN EXPERIMENT**

by

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# ASSESSING AND RANKING MULTI-ATTRIBUTE DECISION ALTERNATIVES: AN EXPERIMENT

by

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## ABSTRACT

This thesis documents the collection and analysis of experimental data used to compare and contrast three methods of evaluating attribute choices that have no natural measurement basis. Attribute choice evaluation is prerequisite to ranking and evaluating multi-attribute decision alternative sets. Data for the methods center on subjective inputs from subject matter experts. The particular experiment collected response data from 27 experts in the United States Navy LAMPS (Light Airborne Multipurpose System) helicopter community attached to the Naval Postgraduate School. The pilots compared three helicopter systems (attribute choices) in each of four system categories (attributes); weapons, navigation systems, communication systems, and sensors. The complete procedure would evaluate every feasible helicopter system suite (decision alternative set), each set composed of one attribute choice from every attribute, facilitating ordinal ranking of the sets. Thesis results present consistency analyses of the experts' responses within, and between, the three methods of determining attribute choice values.

## TABLE OF CONTENTS

## LIST OF SYMBOLS, ACRONYMS AND/OR ABBREVIATIONS

| | |
|---|---|
| ASST | Anti-Ship Surveillance and Targeting |
| ASUW | Anti-Surface Warfare |
| ASW | Antisubmarine Warfare |
| ATO | Airborne Tactical Officer |
| AW | Aviation Antisubmarine Warfare Operator |
| BDA | Battle Damage Assessment |
| $b_{norm}$ | Normalized Bias Parameter |
| $C^3I$ | Command, Control, Communications and Intelligence |
| $d^2$ | Mean Squared Difference |
| d | Dispersion Parameter |
| $d_{norm}$ | Normalized Dispersion Parameter |
| DASH | Drone Antisubmarine Helicopter |
| ESM | Electronic Support Measures |
| FLIR | Forward Looking Infrared |
| GPS | Global Positioning System |
| IFF | Identification, Friend or Foe |
| LAMPS | Light Airborne Multipurpose System |
| MAD | Magnetic Anomaly Detector |
| MEDEVAC | Medical Evacuation |
| NSFS | Naval Surface Fire Support |
| SAR | Search and Rescue |
| SATCOM | Satellite Communications |
| TACAN | Tactical Air Navigation |
| USW | Undersea Warfare |
| VERTREP | Vertical Replenishment |

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## EXECUTIVE SUMMARY


Military decision makers are constantly challenged to make optimal choices between competing alternatives. This challenge is made even more demanding in that, often, competing alternatives are very complex and have no natural measurement basis from which to conduct direct comparisons. By sufficiently dividing each of the complex alternatives into characteristics, called attributes, common to all, or at least most, of the alternatives, direct comparisons and evaluations of each alternative's particular attribute, called attribute choices, might be made. By weighting the importance of each of the attributes, a value for each of the competing alternatives can be calculated and direct quantitative comparisons made.

This thesis focuses on the first major step of the overall process; evaluating attribute choices with no natural measurement basis. Three methods of determining attribute choice values which use subject matter expert subjective inputs were compared and contrasted. Experiment response data from 27 experts in the United States Navy LAMPS (Light Airborne Multipurpose System) helicopter community were examined for response consistency within and between the three methods.

The three methods examined to evaluate attribute choices involved direct evaluation via a linear scale, and indirect evaluation via pairwise comparisons and indifference probabilities. Derived data values were plotted versus directly obtained values. The amount and characteristic behavior (bias) of the derived values' dispersion from the directly obtained values within and between each of the methods were calculated and compared.

The smaller the magnitudes of dispersion and bias, the more consistent the responses. The intra-method consistency checks in the table indicate that while the pairwise comparison method showed the least dispersion, it was more susceptible to bias than the indifference probability method. The same conclusions seemingly can be drawn from

| **Intra-method Consistency Checks** | **Dispersion, $d_{norm}$** | **Bias, $b_{norm}$** |
|---|---|---|
| Pairwise Comparisons | 0.0299 | +0.1401 |
| Indifference Probabilities | 0.1851 | +0.0420 |
| **Inter-method Consistency Checks** | **Dispersion, $d_{norm}$** | **Bias, $b_{norm}$** |
| Marking a Linear Scale vs Pairwise Comparisons | 0.0361 | -0.2264 |
| Marking a Linear Scale vs Indifference Probabilities | 0.2968 | -0.0862 |
| Pairwise Comparisons vs Indifference Probabilities | 0.3962 | -0.2052 |

the inter-method consistency checks; however, method interaction prevents definite inferences from being made.

Additional consistency checks seemed to imply the experts were risk prone when they perceived there was little to loose and much to gain. Conversely, the experts were risk averse when they perceived there was much to loose and little to gain.

# I. INTRODUCTION

## A. THESIS SCOPE AND GOALS

This thesis documents the collection and analysis of experimental data used to compare and contrast three methods of evaluating attribute choices that have no natural measurement basis. Attribute choice evaluation is prerequisite to ranking and evaluating multi-attribute decision alternative sets. Data for the methods center on subjective inputs from subject matter experts. The particular experiment collected response data from 27 experts in the United States Navy LAMPS (Light Airborne Multipurpose System) helicopter community attached to the Naval Postgraduate School.

These LAMPS pilots were asked to compare three helicopter systems (attribute choices) in each of four system categories (attributes); weapons, navigation systems, communication systems, and sensors. The complete procedure would evaluate every feasible helicopter system suite (decision alternative sets), facilitating their ordinal ranking. It should be emphasized that this thesis concentrates on consistency analyses within and between the three methods of determining attribute choice values. It is not the goal nor intent of this thesis to evaluate LAMPS helicopter system suites.

## B. THESIS OUTLINE

Chapter II provides definitions of multi-attribute decision alternative sets, attributes, and attribute choices, and an overview of how these elements are combined to evaluate decision alternative sets. The employment of subjective inputs from subject matter experts is then

discussed. The bulk of the chapter concentrates on describing the three attribute choice evaluation methods. Techniques used to apply the methods are discussed, as are ways to conduct intra and inter-method consistency checks.

Chapter III highlights the experimental approach used to collect the thesis data. Also included is a brief discussion of the history and current mission applications of LAMPS. This discussion is meant to give the reader unfamiliar with LAMPS some insight into the experimental survey setup and question design. In view of the broad range and variety of missions performed by LAMPS, the importance of and reasoning behind presenting the pilots with a standardized, albeit generalized, mission are also discussed. The specific attributes and attribute choices used for the experiment are then presented, along with samples of the 81 possible helicopter system suites that could be created. The chapter finishes with an overview of the survey response form and guide, and a discussion on the actual administration of the surveys.

The methods used to analyze the data, specifically intra and inter-method consistency checks, are described in Chapter IV. Consistency check plots, along with the two parameters used to quantitatively measure consistency, are derived and results for five main data subsets are presented. Tables summarizing the consistency check parameters for 28 various data subsets conclude the chapter.

Chapter V concentrates on interpreting the consistency check parameters developed in Chapter IV for the five main data subsets. Some consistency checks that yielded unexpected results are analyzed in greater detail and utility function theory applied in an attempt to explain

the results. The thesis closes with discussions on method applicability, experiment conclusions and suggested areas for future study.

# II. MULTI-ATTRIBUTE DECISION ALTERNATIVE SETS WITH NO NATURAL MEASUREMENT UNITS

Chapter II opens by providing definitions of multi-attribute decision alternative sets, attributes, and attribute choices, and an overview of how these elements are combined to evaluate decision alternative sets. The employment of subjective inputs from subject matter experts is then discussed. The bulk of the chapter concentrates on describing the three attribute choice evaluation methods. Techniques used to apply the methods are discussed, as are ways to conduct intra and inter-method consistency checks.

## A. DEFINITIONS

To fully comprehend the evaluation methods described later in this chapter, the following definitions should be thoroughly understood:

- **Multi-Attribute Decision Alternative Set**: Also called a *decision alternative, alternative set*, or *set*, a multi-attribute decision alternative set is a complex object upon which a decision maker wants to place a quantitative value in order to directly compare it with similar complex objects. For example, an auto dealership may present a perspective car buyer (i.e., a decision maker) with dozens of alternative sets (i.e., cars) that he wants to evaluate.
- **Attribute:** An *attribute* is an alternative set *characteristic* common to all (or at least most) of the sets considered for evaluation and ranking. For example, attribute candidates

for new cars could include gas mileage and exterior color. Note that some attributes (e.g., gas mileage) are much easier to quantify than others (exterior color).

- **Attribute Choice:** An *attribute choice*, or *choice*, is the particular item or characteristic of a certain attribute in each alternative set. For the car example, attribute choices for the exterior color attribute may be green, red, and black for some car models, and silver, dark blue, red, and turquoise for others. The gas mileage attribute choice for one model of car might be 17.9 miles per gallon (mpg) and 24.1 mpg for a different model. Note that the number of attribute choices need not be the same for each attribute (six exterior color attribute choices, but only two gas mileage choices). Also note that not all alternative sets may be available or feasible (the dealer may not have a red car that gets 24.1 mpg).

## B. PROBLEM STATEMENT AND FORMULATION

This thesis examines and checks the consistency of three attribute choice evaluation methods that are prerequisite for evaluating alternative sets that have no natural basis for comparison. The absence of a natural comparison basis creates questions of how to place an overall value on alternative sets and, ultimately, how to consistently choose the best alternative set.

Rather than try to compare alternative sets considering all attributes simultaneously, the sets are broken down into single attribute choices upon which the methods are then used to derive attribute choice values

and attribute weighting factors. From these, an overall value for each alternative set is then calculated.

Assume that there are m alternative sets and that each alternative set has n attributes. The alternative sets are indexed by $j = 1, 2, ..., m$, and the attributes by $i = 1, 2, ..., n$. Let $V_i(j)$ be the amount of value obtained from attribute i in alternative set j. The overall value of set j is assumed to be given by Equation (1):

$$V(j) = \sum_{i=1}^{n} \alpha_i V_i(j) \quad \text{for any } j = 1, 2, ..., m, \text{ where} \tag{1}$$

$V(j)$ = overall value for alternative set j;

$\alpha_i$ = weighting factor for attribute i; $\alpha_i$ is the amount of set j's overall value obtained from a unit of attribute i;

$\alpha_i > 0$ if, for attribute i, bigger is better [Ref. 1, Table 7.2]; and,

$\alpha_i < 0$ if, for attribute i, smaller is better; and,

$V_i(j)$ = value of attribute i for alternative set j.

Given the $V_i(j)$'s and $\alpha_i$'s, the overall numerical values for each of the alternative sets, the $V(j)$'s, can be calculated. Once the $V(j)$'s have been found, they can be ranked to find the alternative set with the greatest overall value. Mathematically the objective is to find

$$\text{Max}_j \; \{ V(j) = \alpha_1 V_1(j) + \alpha_2 V_2(j) + ... + \alpha_n V_n(j) \}^1 . \tag{2}$$

---

[1] Appendix A provides a more in-depth discussion of the nomenclature and indexing relationships used throughout this thesis. If the reader continues to have questions regarding the interrelationships of Equation (1) and (2) components, he should refer to Appendix A at this time.

Numerical values for each of the $V_i(j)$'s and $\alpha_i$ 's, however, are generally not readily available. Before the alternative sets can be ranked, these values must be determined.

This thesis takes an experimental approach to test decision maker response consistency within and between three methods for deriving the $V_i(j)$'s. For future study, data was also collected to examine expert response consistency in deriving $\alpha_i$ 's.

## C. SUBJECT MATTER EXPERT SUBJECTIVE INPUTS

Deriving a value for an attribute choice may be a matter of taking a simple physical measurement, such as temperature or volume. Many attributes, however, do not lend themselves as readily to evaluation, or are very time consuming or expensive to evaluate. Attribute weighting factors are even less easily obtained.

This thesis compares several methods for deriving attribute choice values. The methods make use of subjective inputs from subject matter experts (also called *decision makers*, or *experts*). For each attribute, experts are asked to rank the attribute choices from the one with the most preferred level to the one with the least preferred level.

Having ordinally ranked the attribute choices for each attribute, experts are asked to compare the choices in the following three ways:

For each attribute:

- assign a *value* to each attribute choice from a linear scale (Method 1);
- make pairwise comparisons of attribute choices by

assigning a number to the *ratio of* their *values* (Method 2); and,

- find an *indifference probability* for a gamble between the *best* and *worst* attribute choices and a certainty of obtaining an *intermediate* attribute choice (Method 3).

Using Method 1 the $V_i(j)$'s are obtained directly. Methods 2 and 3 were designed to build in consistency checks within each method.

Experimental results are presented in Chapter IV that demonstrate the levels of consistency within Methods 2 and 3, followed by inter-method consistency checks between Methods 1 and 2, 1 and 3, and 2 and 3.

### D. METHOD STRUCTURES AND CONSISTENCY CHECKS

For each attribute, an expert is asked to provide a series of subjective inputs as to which choice possesses the most preferred level of that attribute, the second most preferred level, and so on down to the attribute choice with the least preferred level of that attribute. The expert then uses the three methods to quantify the degree to which each choice's attribute level differs from the remaining choices. Finally, these responses, and those to develop attribute weighting factors, could be applied to evaluate decision alternatives. Again, this thesis does not attempt to evaluate decision alternatives, rather, the degree of expert response consistency within and between the three attribute choice evaluation methods is examined.

### 1. Data Acquisition Steps; Comparison Methods and Consistency Checks

A series of responses is required of the expert in order to collect data to derive attribute choice values.

#### *a. Step 1: Attribute Choice Subjective Rankings*

For each attribute, the expert ranks the attribute choices from the one with the most preferred level (i.e., the *best* choice) of an attribute, to the one with the least preferred level (i.e., the *worst* choice) of that attribute. For example: if the attribute under consideration is *gift stature*, and the attribute choices are a $5.00 gift, $20.00 gift, or $100.00 gift, then the expert would likely rank the $100.00 gift attribute choice as having the most preferred level of *gift stature* attribute, the $20.00 gift as having less of the attribute than the $100.00 gift, but more than the $5.00 gift, and the $5.00 gift last for having the least preferred level of the attribute *gift stature*. Symbolically, $100.00 gift ≻ $20.00 gift ≻ $5.00 gift, where the symbol ≻ indicates the choice to the left of the symbol is *preferred* to the choice to the right of the symbol. The symbol does not represent *greater than*.

Responses for Step 1 are inherently consistent. They would become inconsistent only if the expert later decided his initial rank order did not correctly represent his opinion. If the expert changes his initial rank order *before* he completes all the data collection steps, the data collection process must be restarted at Step 1.

#### *b. Step 2: Marking a Linear Scale (Method 1)*

The expert is next asked to quantify the attribute choices using the three methods discussed earlier in Section C of this chapter. Using the first method, designated Method 1, the expert derives attribute

choice values *directly* by marking a linear scale labeled from zero, representing an attribute choice with an absolutely worthless value, to 100, representing an attribute choice with the best possible value. Figure 1 shows an example of such a scale and a possible set of responses to the *gift stature* attribute example introduced in the previous section.

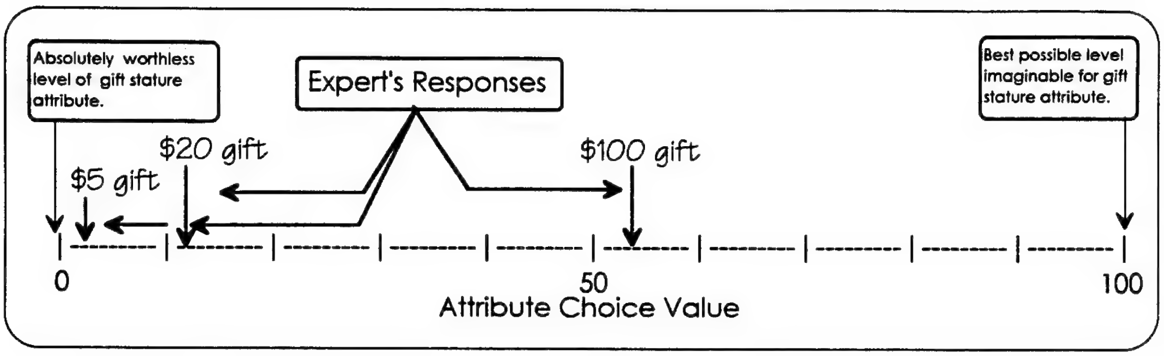


Figure 1. Example of Method 1 (Step 2), Marking a Linear Scale.

Method 1 responses, considered by themselves, are inherently consistent and would become inconsistent only if the expert changes his rank ordering established in Step 1.

**c. *Step 3: Attribute Choice Pairwise Comparisons (Method 2)***

The second method by which the expert is asked to quantify the attribute choices, designated Method 2, is a process of pairwise comparisons between all attribute choices within each attribute. This method provides attribute choice values *indirectly* via ratios of attribute choice values. The expert is asked to give his opinion on the *relative value* of *how much better* (more valuable, more preferred, etc.) each *best* attribute choice is over the attribute choice with the *second best* level of the attribute, third best, and so on down to the attribute choice with the worst level of the attribute, as ranked during Step 1. He then

compares the second best to the third best and so on down to the worst. This process is continued until all possible pairwise comparison combinations of attribute choices of each attribute are considered. The expression for the pairwise comparison ratio is shown in Equation (3):

$$r_{kl} = \frac{V_k}{V_l} = \text{ratio of the values of attribute choices k and l, where} \quad (3)$$

$V_k$ = value of attribute choice k, and

$V_l$ = value of attribute choice l, and

$V_k > V_l$ .

If $K_i$ is the number of attribute choices within attribute i, then the required number of comparisons is $\frac{K_i!}{2!(K_i-2)!} = \frac{K_i(K_i-1)}{2}$ .

Figure 2 demonstrates an example set of pairwise comparisons (Step 3, Method 2) with the three attribute choices for the attribute *gift stature* discussed earlier.

A technique for checking the expert's Method 2 response consistency starts by plotting data on an (X, Y) plot. Let $r_{bi}$, $r_{iw}$, and $r_{bw}$ be the expert's responses for the pairwise comparison ratios of the best versus intermediate, intermediate versus worst, and best versus worst attribute choices, respectively. Now plot the expert's response for $r_{bw}$ on the X-coordinate. From Equation (3) we know $r_{bi} = \frac{V_b}{V_i}$, and $r_{iw} = \frac{V_i}{V_w}$. The product of these two ratios reduces to a derived value for $r_{bw}$ and is plotted on the Y-coordinate. If the expert is perfectly consistent in his responses, $r_{bi}r_{iw} = \left(\frac{V_b}{V_i}\right)\left(\frac{V_i}{V_w}\right) = \frac{V_b}{V_w} = r_{bw}$ , and the plotted data point will lie on a line through the origin of slope 1.0. A quick visual consistency

check then notes the displacement, if any, of the plotted data point from the line drawn through the origin with slope 1.0.

Give your quantitative opinions on how much *better* the *best* attribute choice is over the *intermediate* and *worst* attribute choices, and how much *better* the *intermediate* attribute choice is over the *worst*.

- **Attribute: Gift Stature**
- **Attribute Choices:** Best: $100 gift Intermediate: $20 gift Worst: $5 gift

Expert's responses...

Ratio of best to intermediate: $r_{bi} = V_b / V_i$

- The (Best) $100 gift is 5 times *better* (more valuable) than the (Intermediate) $20 gift.
- The (Best) $100 gift is 19 times *better* (more valuable) than the (Worst) $5 gift.
- The (Intermediate) $20 gift is 3.5 times *better* (more valuable) than the (Worst) $5 gift.

Figure 2. Example of Method 2 (Step 3), Attribute Choice Pairwise Comparisons.

Quantitative measures of response consistency involve calculating the vertical bias and mean squared difference of the data points from the slope 1.0 line. Equations for calculating these measures are discussed in Chapter IV, Section A. Figure 3 shows a consistency check plot of $r_{bi}\, r_{iw}$ versus $r_{bw}$ for the example data in Figure 2.

### d. Step 4: Attribute Choice Indifference Probabilities (Method 3)

Method 3 (Step 4) is the third and final method used to quantify the expert's attribute choice preferences, and involves acquiring

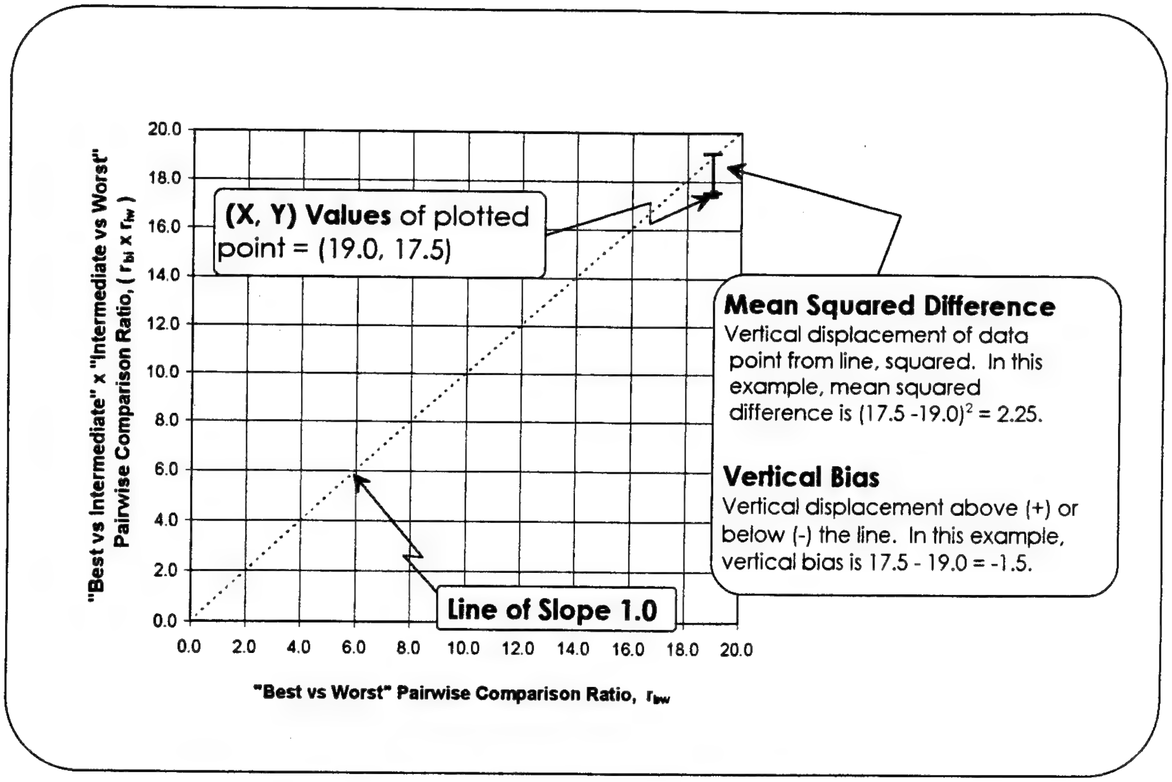


Figure 3. Checking Consistency of Method 2 Responses.

the expert's attribute choice *indifference probability*. Perhaps the easiest way to define an *indifference probability* is with a decision tree.

Figure 4 shows a simple decision tree, or decision sapling [Ref. 1]. The square node on the left side of the diagram is a *decision node*, the round one is a *chance node*, and the diamond shaped nodes are *result nodes*. The result node labels $V_b$, $V_i$, and $V_w$ are the *values* of the *best*, *intermediate*, and *worst* attribute choices, respectively, for a given attribute. The decision maker starts at the decision node and moves from left to right along one and only one path until he reaches a result node. There is no risk involved for the expert if he chooses to follow the upper branch. Upon reaching the result node he will receive a value $V_i$. He may, on the other hand, choose to take the lower branch. Upon

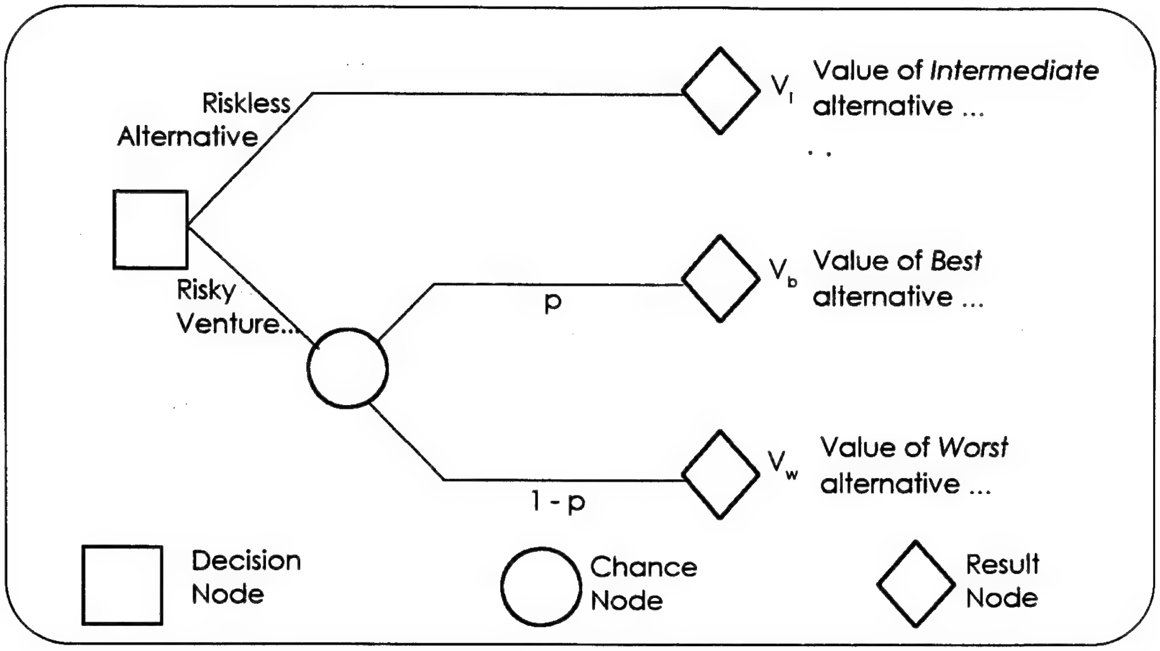


Figure 4. Sample of a Decision Sapling.

reaching the chance node, there is a *chance*, p, he will take the upper branch out of the chance node and receive a value $V_b$, or a chance (1 - p) that he will follow the lower branch and receives a value $V_w$. The *indifference probability* is the value of p for which the decision maker is indifferent between taking the gamble and taking the riskless alternative.

Figure 5 shows an example of a type of problem that could be posed to an expert to determine his indifference probability. The example uses the same attribute (gift stature) and attribute choices ($100.00 gift (best); $20.00 gift (intermediate); and $5.00 gift (worst)) as in previous examples.

A technique for checking consistency within Method 3 requires two responses for each attribute. The expert first provides a response to the original indifference probability problem as demonstrated

•You currently have the (Intermediate) $20.00 gift. You may keep it, or you may use it to gamble for the (Best) $100.00 gift. If you gamble and win, you get the (Best) $100.00 gift. If you gamble and loose, you get the (Worst) $5.00 gift. If you do not gamble at all, you keep the (Intermediate) $20.00 gift.

•What is the ***minimum*** ***percentage chance of winning the*** (Best) $100.00 gift you are willing to accept in order to take the gamble?

Expert's Response, (**p** x 100) • 20 percent

Figure 5. Sample Method 3 (Step 4) Problem to Induce Expert's Indifference Probability, p.

in Figure 5. The expert then provides a second response to an indifference probability problem that could be considered the *inverse* of the original. The expert's response to the first indifference probability problem is plotted on the X-coordinate, while one minus the corresponding response from the second indifference probability problem is plotted on the Y-coordinate. Figure 6 demonstrates an example of a second attribute choice indifference probability problem corresponding to the first problem in Figure 5.

•You currently have the (Intermediate) $20.00 gift. You may keep it, or you may use it to gamble for the (Best) $100.00 gift. If you gamble and win, you get the (Best) $100.00 gift. If you gamble and loose, you get the (Worst) $5.00 gift. If you do not gamble at all, you keep the (Intermediate) $20.00 gift.

•What is the ***maximum*** ***percentage chance of getting the*** (Worst) $5.00 gift you are willing to accept in order to take the gamble?

Expert's Response, (**q** x 100) • 70 percent

Figure 6. Sample Method 3 (Step 4) Problem to Induce Second Attribute Choice Indifference Probability, q.

The indifference probability equates the expected values out of either branch of the decision node in the decision sapling such that the expert is indifferent between taking the riskless branch or the risky venture. When

$$V_i = pV_b + (1-p)V_w, \quad \text{where } p = \Pr\{\text{win}\}, \tag{4}$$

$$V_i = (1-q)V_b + qV_w, \quad \text{where } q = \Pr\{\text{loose}\}, \text{ and} \tag{5}$$

$V_b, V_i, V_w$ = values of best, intermediate and worst attribute choices, respectfully,

the expert is perfectly consistent. Figure 7 shows a consistency plot for the responses given in the examples in Figures 5 and 6. Note that if the expert

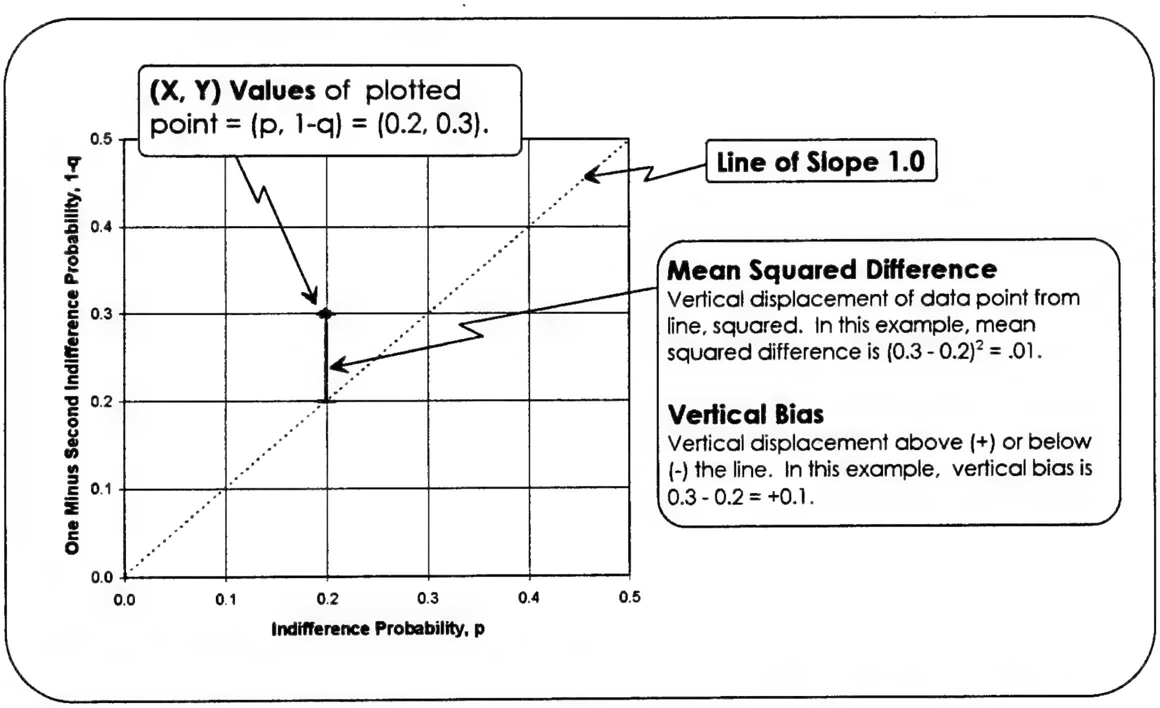


Figure 7. Method 3 (Step 4) Indifference Probability Intra-Method Consistency Check.

is *perfectly consistent* with his responses, then

$$p = (1 - q). \tag{6}$$

### 2. Inter-Method Consistency Checks

Inter-method consistency check procedures are presented in the following subsections. As with the intra-method consistency checks, these checks involve plotting data on an (X, Y) plot. If the expert is *perfectly consistent*, a line drawn from the origin through the (X, Y) data point should have a slope of 1.0.

#### *a. Consistency Check Between Methods 1 and 2*

The first inter-method consistency check compares the expert's responses to Method 1 (marking a linear scale) and Method 2 (attribute choice pairwise comparisons). The expert's Method 2 responses, the $r_{kl}$'s, are plotted on the X-coordinate. The corresponding calculated ratios of values from Method 1 are plotted on the Y-coordinate. For example, from Figure 2, the expert's response for the best versus worst pairwise comparison was 19. From Figure 1, the ratio of the best attribute choice value, $V_b$, versus the worst attribute choice value, $V_w$, was $\frac{V_b}{V_w} = \frac{54}{3} = 18$. If the expert was perfectly consistent *between methods* the plotted point should lie on a line through the origin of slope 1.0. Figure 8 shows the inter-method consistency check for the data from the figures mentioned above.

#### *b. Consistency Check Between Methods 1 and 3*

A method for checking consistency between Methods 1 and 3 is now discussed. The relationship between p and the ratio of value differences is first derived. From Equation (4),

$$V_i = pV_b + (1-p)V_w\,,$$
$$= pV_b - pV_w + V_w\,,$$
$$(V_i - V_w) = p(V_b - V_w).$$
$$\text{Thus} \quad p = \frac{(V_i - V_w)}{(V_b - V_w)}\,. \tag{7}$$

Each p is plotted on the X-coordinate and the corresponding $\frac{(V_i - V_w)}{(V_b - V_w)}$ on the Y-coordinate. Again, if the expert is perfectly consistent between methods, the plotted points will lie directly on a line through the origin of slope 1.0.

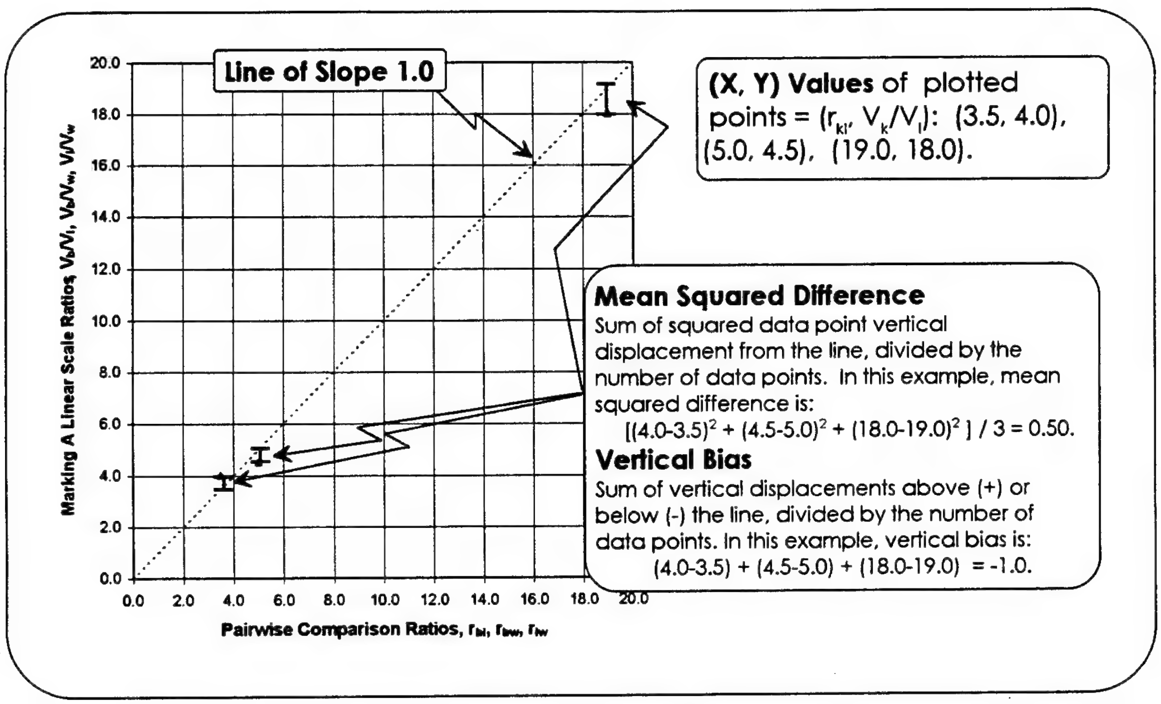


Figure 8. Inter-Method Consistency Check between Methods 1 and 2, Marking a Linear Scale versus Attribute Choice Pairwise Comparisons.

Figure 9 shows a consistency plot of the Methods 1 and 3 sample data from Figures 1 and 5. Note that since probabilities are being plotted, the scales on this consistency plot are values between 0.0 and 1.0, unlike the previous inter-method consistency plot which is scaled by ratios of attribute values.

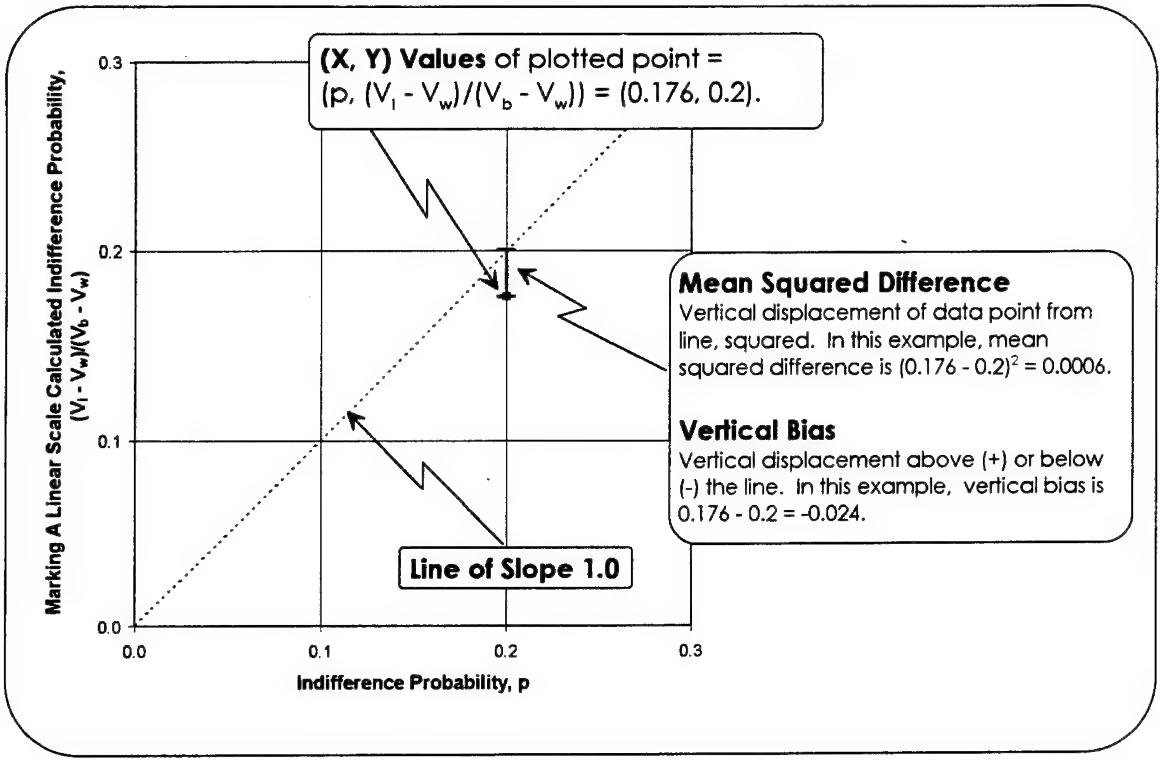


Figure 9. Inter-Method Consistency Check between Methods 1 and 3, Marking a Linear Scale versus Attribute Choice Indifference Probabilities.

### c. *Consistency Check Between Methods 2 and 3*

The third and final inter-method consistency check compares the expert's responses between Methods 2 and 3. From Equation (7),

$$p = \frac{(V_i - V_w)}{V_b - V_w)} \quad ,$$

$$= \frac{(\frac{1}{V_w})(V_i - V_w)}{(\frac{1}{V_w})(V_b - V_w)} \quad ,$$

$$p = \frac{r_{iw} - 1}{r_{bw} - 1} \quad . \tag{8}$$

The value of p is plotted on the X-coordinate, and the ratio $\frac{(r_{iw}-1)}{(r_{bw}-1)}$ on the Y-coordinate. A consistency plot of the Methods 1 and 3 sample data would look very similar to Figure 9.

This chapter provided definitions of multi-attribute decision alternative sets, attributes, and attribute choices, and an overview of how these elements are combined to evaluate decision alternative sets. The employment of subjective inputs from subject matter experts was discussed, as were three methods for evaluating attribute choices. A presentation of the techniques used to apply the methods, along with ways to conduct intra and inter-method consistency checks, concluded the chapter.

Chapter III goes into detail on the experimental approach utilized for this thesis.

# III. EXPERIMENTAL APPROACH

Chapter III highlights the experimental approach used to collect the thesis data. Also included is a brief discussion of the history and current mission applications of LAMPS. The importance of and reasoning behind presenting the pilots with a standardized, albeit generalized, mission are also discussed. The specific attributes and attribute choices used for the experiment are then presented, along with samples of the 81 possible helicopter system suites that could be created. The chapter finishes with an overview of the survey response form and guide, and a discussion on the actual administration of the surveys.

## A. UNITED STATES NAVY LAMPS HELICOPTER PILOT SUBJECT MATTER EXPERT DECISION MAKERS

United States Navy LAMPS (Light Airborne Multi-Purpose System)[1] helicopter pilots were selected to be the *subject matter experts* (i.e., *decision makers*) for an experimental application of the methods described in Chapter II due to the author's extensive experience and familiarity with the LAMPS community. A total of 27 LAMPS pilots assigned to the Naval Postgraduate School were individually administered a survey to solicit their expert judgements on the *value* of three pieces of helicopter equipment (*attribute choices*) in each of four different equipment categories (*attributes*). The survey also queried the subject matter experts to solicit data for developing equipment category *weighting factors* (*attribute weighting factors*) for possible future analysis.

---

[1] Both U. S. Navy LAMPS Mk I and LAMPS Mk III helicopter pilots were surveyed for this thesis. LAMPS Mk I pilots operate the SH-2F/G *Seasprite*, while LAMPS Mk III pilots operate the SH-60B *Seahawk*.

Data processing and analysis of the experts' responses, especially response consistency checks, are presented in Chapters IV and V.

The reader is reminded that it was *not* the intent of this thesis to develop values or weighting factors for LAMPS equipment, systems, or system suites, rather it was to exercise and check for expert response consistency of the methods presented in Chapter II.

## B. WHAT IS LAMPS?

LAMPS' ancestor was conceived in the late 1950's in the form of DASH (Drone Anti-Submarine Helicopter). DASH was an unmanned, radio controlled, torpedo carrying helicopter designed to deliver USW (UnderSea Warfare) weapons at convergence zone ranges, well beyond the five mile range of the parent ship. Deployed from USW ships, DASH was originally *semi-* expendable, which is just as well as few DASH's lived beyond a few flights.

As torpedo size increased, so did the payload requirements, size and costs of DASH. By the late 1960's, DASH's costs no longer justified expendability. By this time, helicopter and powerplant technology had matured to the point where manned helicopters could be deployed from surface combatants. In 1971, LAMPS Mk I was born in the form of the SH-2F *Seasprite*. In its infancy, LAMPS Mk I was a marriage of off-the-shelf sensor and avionic systems with previously boneyarded airframes. It was an enormously successful relationship and the Navy quickly recognized the synergistically enhanced capabilities of a ship-helicopter system.

In 1975, IBM won the System Integration Program contract to design LAMPS Mk III from the ground up. The LAMPS Mk III SH-60B *Seahawk* first deployed in 1984 and is the airborne component of a fully-integrated

ship-helicopter weapon system. The helicopter is crewed by a pilot, ATO (Airborne Tactics Officer), and an enlisted sensor operator (AW rating). It is highly capable of autonomous operations with all of its sensors and weapons, including radar, sonobuoys, MAD (Magnetic Anomaly Detector), IFF (Identification Friend or Foe), ESM (Electronic Support Measures), torpedoes, and Penguin Missiles.

The helicopter is only half the story, however, as many of the airborne sensors' capabilities are greatly enhanced through a dedicated datalink to a LAMPS Team embarked in the parent ship. The ship's greater data processing and analysis capabilities, especially for sonar and ESM data, along with greater $C^3I$ (Command, Control, Communications and Intelligence) capability, make for a truly synergistic system.

LAMPS was first cast primarily as an USW platform. Today LAMPS' two primary missions are ASUW (Anti-SUrface Warfare) and USW. The ever-growing list of secondary missions is expansive, and includes ASST (Anti-Ship Surveillance and Targeting), NSFS (Naval Surface Fire Support), SAR (Search And Rescue), VERTREP (VERTical REPlenishment), and MEDEVAC (MEDical EVACuation), to name a few.

Currently the LAMPS Mk I is being phased out of the fleet, while the Mk III is deployed extensively, embarked in Ticonderoga Class Cruisers (CG-47), Spruance (DD-963) and future Arleigh Burke (DDG-51) Class Destroyers, and Oliver Hazzard Perry Class Frigates (FFG-7). [Refs. 2 - 6]

## C. STANDARDIZED MISSION

In view of the wide range and variety of missions performed by LAMPS aircrews, and the numerous significant operational and tactical considerations that dictate which helicopter systems to use and how to

employ them given a specific mission, a standardized mission was presented to the LAMPS pilots from which to reference their responses.

The standardized mission presented to the LAMPS pilots was a generic USW mission[2]. Before taking the survey, pilots were briefed to tailor their responses in reference to a *complete* USW mission; i.e., from the *redetection phase* all the way through to completion of the *battle damage assessment* (BDA) *phase*. Pilots were repeatedly reminded throughout the survey to reference their responses to a complete USW mission. Pilot response in reference to a *generalized* USW mission was selected over presenting a more detailed mission scenario to avoid possible complications caused by information overload. It was felt that giving further mission scenario details (e.g., target type (nuclear or diesel submarine), weather conditions, water characteristics (depth, temperature gradients, salinity, biologics, etc.), area (littoral or blue water), etc.), would generate more confusion than clarification.

## D. EXPERIMENT ATTRIBUTES, ATTRIBUTE CHOICES, AND MULTI-ATTRIBUTE DECISION ALTERNATIVE SETS

Four LAMPS helicopter system categories vital to the successful execution of a complete USW mission were presented to the pilots. The four system categories, *weapons, navigation systems, communication systems*, and *sensors*, made up the *attributes* for the methods described in Chapter II. Each of these attributes was comprised of three different system options (i.e., the *attribute choices*). Table 1 lists the attributes and corresponding attribute choices used in the survey.

---

[2] USW is a relatively new term to represent what historically has been called Anti-Submarine Warfare or ASW.

| | **Attribute, i** | | | |
|---|---|---|---|---|
| | Weapons, 1 | Navigation Systems, 2 | Communication Systems, 3 | Sensors, 4 |
| **Attribute Choices (abbreviation)** (Note, no ranking implied by table ordering of attribute choices.) | Mk-46 Torpedo (Mk-46) | Global Positioning System (GPS) | Datalink (D/L) | Magnetic Anomaly Detector (MAD) |
| | 500# Depth Charge (500#) | Tactical Air Navigation (TACAN) | Satellite Communications (Sat Com) | Surface Search Radar (Radar) |
| | Mk-50 Torpedo (Mk-50) | Doppler Radar (Dop) | UHF/VHF Radio (Radio) | Forward Looking Infrared (FLIR) |

Table 1. Survey Attributes and Attribute Choices.

Given the LAMPS system categories and individual systems (i.e., the attributes and attribute choices), LAMPS helicopter USW mission *system suites* (i.e., alternative sets) could be formed. Any system suite would be comprised of one individual system option from each of the four system categories. Given four attributes and three attribute choices per category, there would be j = 81 ( $3^4 = 81$ ) possible LAMPS helicopter mission system suites for the pilots to rank. For example:

j = 1; (Mk-46, GPS, D/L, MAD),

j = 2; (Mk-46, GPS, D/L, Radar),

j = 3; (Mk-46, GPS, D/L, FLIR),

j = 4; (Mk-46, GPS, Sat Com, MAD),

⋮ ⋮

j = 81; (Mk-50, Dop, Radio, FLIR).

## E. DATA COLLECTION SURVEY

Copies of the survey instruction guide and survey response form used to collect data are in Appendix B. Each survey was individually administered with the author readily available to answer questions regarding the mechanics or semantics of the survey. The author made every effort to not plant response predispositions in pilots taking the survey. Pilots were *not* told until after completing the survey that their responses would be examined primarily for consistency as opposed to trying to quantify the value of a LAMPS system suite. Most of the 27 pilots taking the survey completed it in 45 $\pm$ 10 minutes. With few exceptions the survey follows the order of steps described in Chapter II.

This chapter presented the experimental approach used to collect data for the thesis, as well as brief discussions of the history and current mission applications of LAMPS. The importance of and reasoning behind presenting the pilots with a standardized mission were also discussed. The specific attributes and attribute choices used for the experiment were presented, along with samples of the 81 possible helicopter system suites that could be created. The chapter closed with an overview of the survey response form and guide, and a discussion on the actual administration of the surveys.

Chapter IV presents the methods used to analyze the data, specifically intra and inter-method consistency checks.

# IV. CONSISTENCY WITHIN AND BETWEEN METHODS

This chapter describes the methods used to analyze the data, specifically intra and inter-method consistency checks. Consistency check plots, along with quantitative consistency measures, are presented for five main data subsets.

## A. CONSISTENCY CHECKS OVERVIEW

Five sets of consistency checks are discussed in this chapter, two intra-method and three inter-method. Each set of checks employs three techniques for analyzing the LAMPS pilots' survey response consistencies. The first technique involves plotting corresponding data subsets on an (X, Y) plot along with a line through the origin of slope 1.0. If the experimental responses are perfectly consistent, all the data points lie on the line. The reader can see in Figures 10 through 14 in the subsequent sections of this chapter that while some of the plots visually indicate a moderate degree of consistency, others appear to show a great deal of inconsistency.

The second consistency check technique examines the square root of the mean squared difference, or dispersion parameter, $\sqrt{d^2} = d$, of the data points' vertical displacement from a line through the origin of slope 1.0. The magnitude of d gives a measure of the degree of consistency. The value of d will be zero if and only if all responses are perfectly consistent. Otherwise d will have a positive value. Equation (9) gives the formulation for the mean squared difference, $d^2$:

$$d^2 = \frac{1}{K}\sum_{k=1}^{K}(y_k - x_k)^2 \quad , \text{ where} \tag{9}$$

$d^2$ = mean squared difference,

K = the number of data points in the subset,

$x_k$ = the X-coordinate of the $k^{th}$ data point, and

$y_k$ = the Y-coordinate of the $k^{th}$ data point.

Suppose the X-coordinate is plotted over a range (0, m), so a consistent point with x = m would be (m, m). The scale can be converted to (0, 1) by dividing each data point by m, so if $d^2_{norm}$ is defined to be the normalized mean squared difference, from Equation (9),

$$d^2_{norm} = \frac{1}{K}\sum_{k=1}^{K}\left(\frac{y_k}{m} - \frac{x_k}{m}\right)^2 = \frac{d^2}{m^2},$$

and the normalized dispersion parameter is

$$d_{norm} = \frac{d}{m}. \tag{10}$$

The units for the graphs shown in Figures 11, 13, and 14 are indifference probabilities and range in magnitude from zero to one. The units for the graphs shown in Figures 10 and 12 are ratios of attribute choice values. The X-coordinate axes for these graphs are limited to 10.0 and the Y-coordinate axes to 20.0. In order to make quantitative comparative statements between consistency checks of different units, the d's for the checks involving attribute choice value ratios were normalized to a (0, 1) scale. This was done by dividing d by m = 10, the maximum value of the X-coordinate axis. After normalizing the ratio unit data to the same scale as the probability unit data, the $d_{norm}$'s from all the data subsets can be compared directly.

The final technique used to examine response consistency calculates the normalized vertical bias, $b_{norm}$, from a line through the origin of slope 1.0. The sign of b indicates to which side of the slope 1.0 line the data is biased. A positive b indicates bias above the line, negative indicates below. The magnitude of $b_{norm}$ indicates the degree to which the data set is biased. Equation (11) gives the formulation for the normalized vertical bias, $b_{norm}$:

$$b_{norm} = \frac{1}{mK}\Sigma_{k=1}^{K}(y_k - x_k) \quad \text{, where} \tag{11}$$

$b_{norm}$ = normalized vertical bias,

m = maximum value for the X-axis,

K = the number of data points in the subset,

$x_k$ = the X-coordinate of the $k^{th}$ data point, and

$y_k$ = the Y-coordinate of the $k^{th}$ data point.

The value of m is 1.0 for the data subsets with indifference probability units, and 10.0 for the data subsets with attribute choice value ratio units.

Appendix C is a tabulation of the raw survey data. Supplementary graphs of numerous data subsets are in Appendix D.

## B. EXPERIMENTAL INTRA-METHOD CONSISTENCY CHECKS

The pilots' responses to Methods 2 and 3, attribute choice pairwise comparisons and indifference probabilities, were examined for intra-method consistency.

### 1. Method 2: Attribute Choice Pairwise Comparisons

Figure 10 presents a graph plotting the *best versus worst* pairwise comparison ratio, $r_{bw}$, directly from the data as the X-coordinate, and the

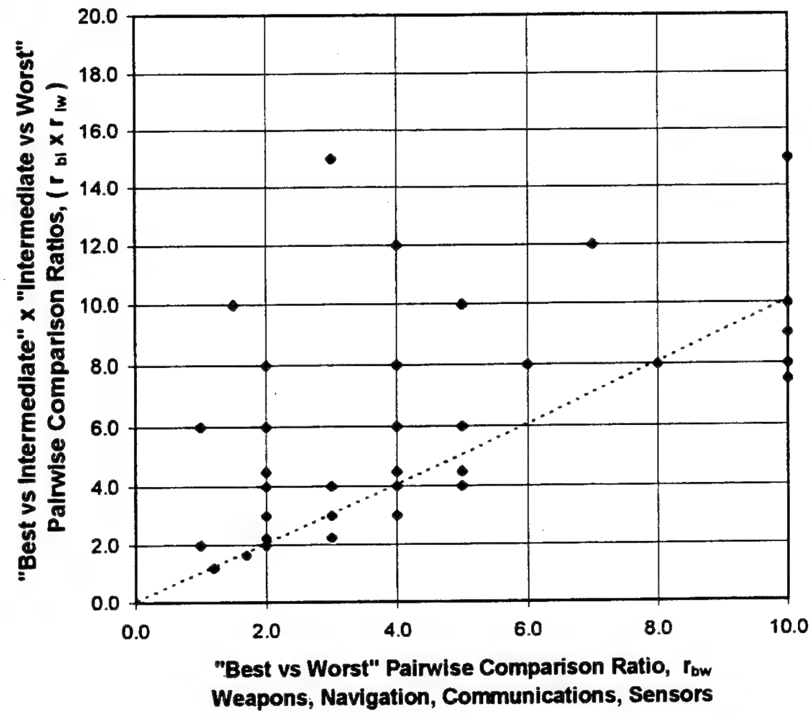


Figure 10. Attribute Choice Pairwise Comparison Intra-Method Consistency Check, all Attributes.

product of the *best versus intermediate* ratio times the *intermediate versus worst* ratio, $r_{bi}\, r_{iw}$, as the corresponding Y-coordinate. This graph presents all the attribute choice pairwise comparison data, within the limits of the graph, from all four attributes (weapons, navigation systems, communication systems, and sensors). Visual inspection of the graph reveals the derived *best versus worst* ratios, the Y-coordinates, are somewhat consistent with the ratios obtained directly, and are definitely biased towards the derived ratios. The plotting method used does not

indicate multiple points in the same location, so it is difficult to get a true visual picture of the amount of consistency or bias. The values of $d_{norm}$ and $b_{norm}$, are 0.0299 and +0.1401, respectively, indicating a high level of consistency, but a moderate level of bias in the answers. Supplementary graphs displaying the data for each of the four attributes are found in Appendix D.

**2. Method 3: Attribute Choice Indifference Probabilities**

Figure 11 presents a plot of the indifference probability, p, directly from the data on the X-coordinate, and the corresponding one minus the second indifference probability, q, as the Y-coordinate. This graph presents all the attribute choice indifference probability data, both first

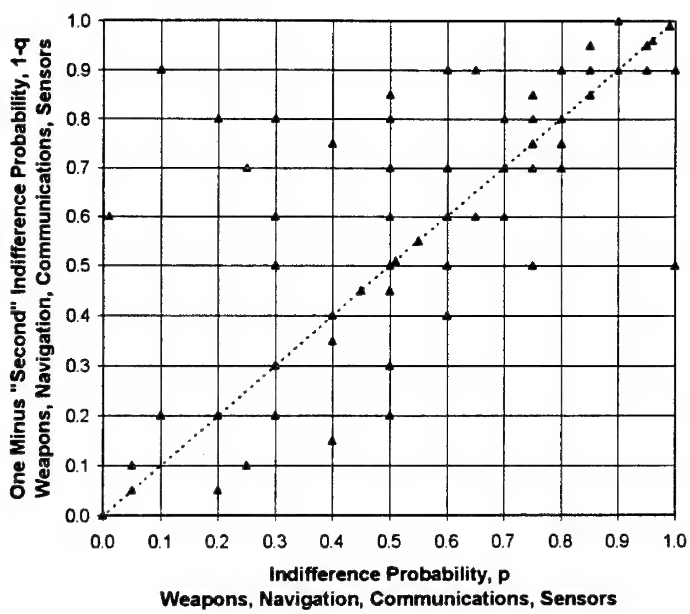


Figure 11. Attribute Choice Indifference Probabilities Intra-Method Consistency Check, all Attributes.

second, from all four attributes. Visual inspection of the graph indicates a less consistent set of responses than with the pairwise comparison data of the previous graph, but a much smaller positive bias as the data is much more evenly spread both above and below the line. For these observations $d_{norm}$ = 0.1851 and $b_{norm}$ = +0.0420. Supplementary graphs displaying the data for each of the four attributes are found in Appendix D.

## C. EXPERIMENTAL INTER-METHOD CONSISTENCY CHECKS

The pilots' responses to all three methods, marking a linear scale, attribute choice pairwise comparisons, and indifference probabilities, were examined for inter-method consistency.

### 1. Between Methods 1 and 2: Marking a Linear Scale versus Attribute Choice Pairwise Comparisons

Figure 12 presents a plot of pairwise comparison data on the X-coordinate, and corresponding ratios of linear scale values from Method 2 on the Y-coordinate (see Equation (3)). The degree of consistency *between* Methods 1 and 2 at first appears to be notably less than the degree of consistency *within* either Methods 1 or 2. A second characteristic difference from the intra-method checks is the vertical grouping of the data points. Intuitively this is explained by the pilots' propensity for integer values when providing ratios of attribute choice values inputs. Over 91 percent of the points on the X-coordinate are integer value.

The value of $d_{norm}$ for this data is only 0.0361, almost the same as the best intra-method value. This result seems to contradict what is displayed graphically, until the data is examined more closely. Over 79

percent of the X-coordinate values are five or less, and nearly 40 percent are two or less (out of 286 data points). The relatively small value for $d_{norm}$ is then somewhat explained by the much larger volume of data points in the groupings in the lower left corner of the graph and close to the slope 1.0 line.

Finally, and not surprisingly looking at the plot, this check was strongly negatively biased with a $b_{norm}$ of (-0.2264). Supplementary graphs displaying the data for each of the four attributes, and for the three types of attribute choice pairwise comparisons, are found in Appendix D.

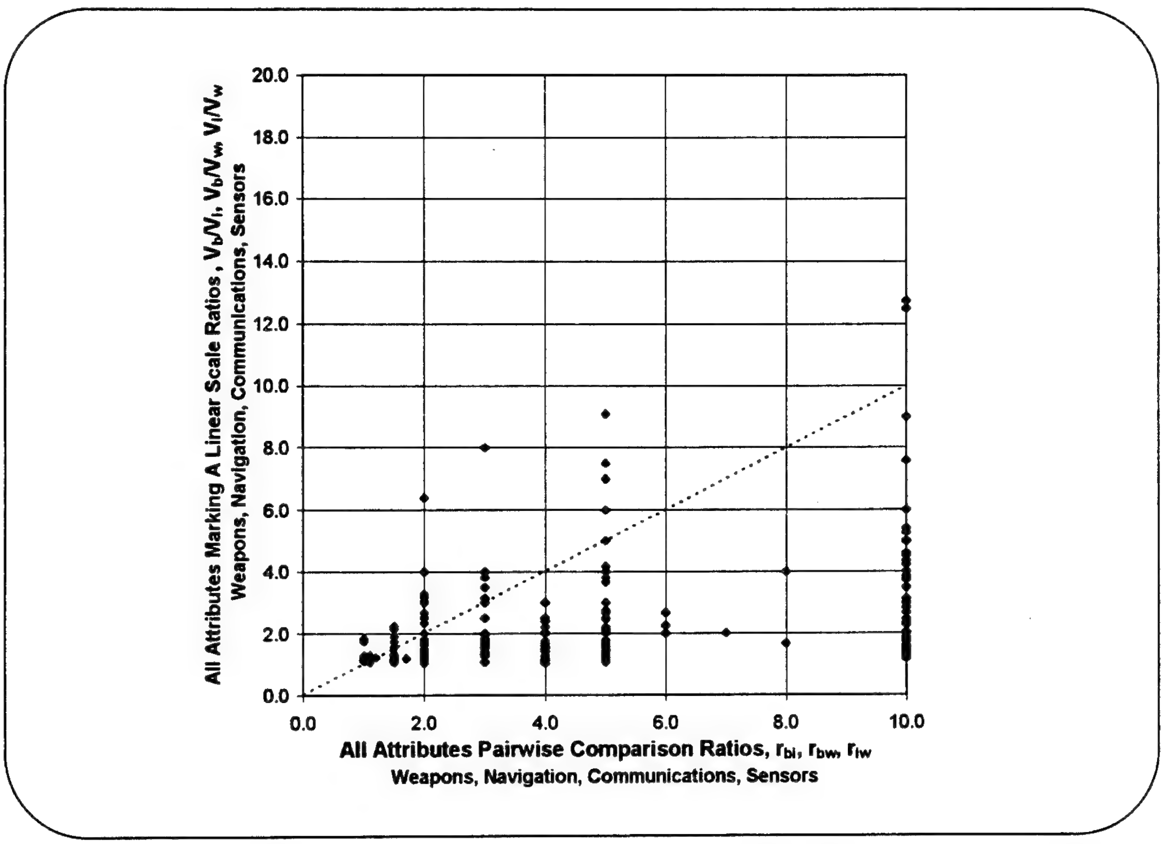


Figure 12. Marking a Linear Scale versus Attribute Choice Pairwise Comparisons Inter-Method Consistency Check, all Attributes.

## 2. Between Methods 1 and 3: Marking a Linear Scale versus Attribute Choice Indifference Probabilities

Figure 13 presents a plot of the indifference probabilities directly obtained from Method 3 on the X-coordinate. The corresponding derived indifference probabilities, from Method 1 data, is plotted on the Y-coordinate (see Equation (7)). This graph also shows some pilot disposition for vertical grouping of data points, though not quite as much as in the previous graph. The raw data for the X-coordinates are percentages. Only three of the 108 X-coordinate inputs are integer

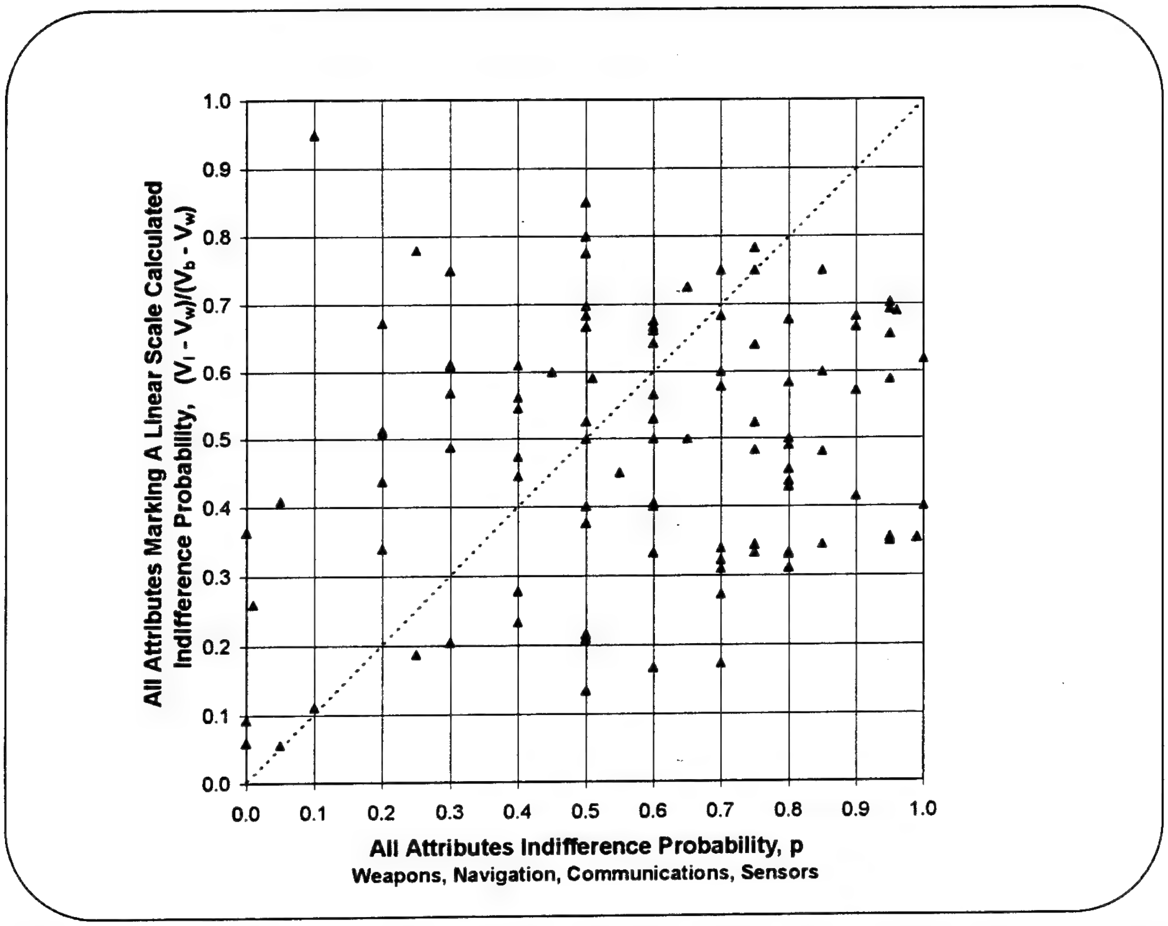


Figure 13. Marking a Linear Scale versus Attribute Choice Indifference Probabilities Inter-Method Consistency Check, all Attributes.

values not divisible by five, and only 30 of the 108 are not divisible by ten. Reviewing the data helps explain why the vast majority of data points fall on the vertical gridlines.

The value of $d_{norm}$ for this check is 0.2968, significantly greater than the three previous consistency check results. Reviewing the graph confirms the large $d_{norm}$ value, seemingly indicating a relatively low level of inter-method consistency between Methods 1 and 3.

Vertical bias is relatively small, as might be expected by the considerable and apparently evenly distributed vertical displacement of the data points on either side of the slope 1.0 line. The value of $b_{norm}$ is (-0.0862), the least biased of the inter-method consistency checks discussed in this chapter. Supplementary graphs displaying the data for each of the four attributes are in Appendix D.

### 3. Between Methods 2 and 3: Attribute Choice Pairwise Comparisons versus Attribute Choice Indifference Probabilities

The final inter-method consistency check compares directly obtained indifference probabilities and corresponding indifference probabilities derived from the attribute choice pairwise comparison method data (see Equation (8)). Figure 14 presents a plot of the directly-obtained indifference probabilities on the X-coordinate and the corresponding derived values on the Y-coordinate. Since this graph has the same inputs for the X-coordinates as the previous graph, it also shows correlation along the vertical gridlines. The graph indicates a rather low level of consistency and a strongly negative bias.

The value of $d_{norm}$ for this check is 0.3962, the largest $d_{norm}$ value of the five consistency checks discussed in this chapter, and greater than all but one of the data subset checks found in Appendix D. Such a large

value of $d_{norm}$ suggests a significant level of response inconsistency between Methods 2 and 3.

The graphical interpretation of the bias is supported by a $b_{norm}$ of (-0.2052), indicating a strongly negative bias. Supplementary graphs displaying the data for each of the four attributes are found in Appendix D.

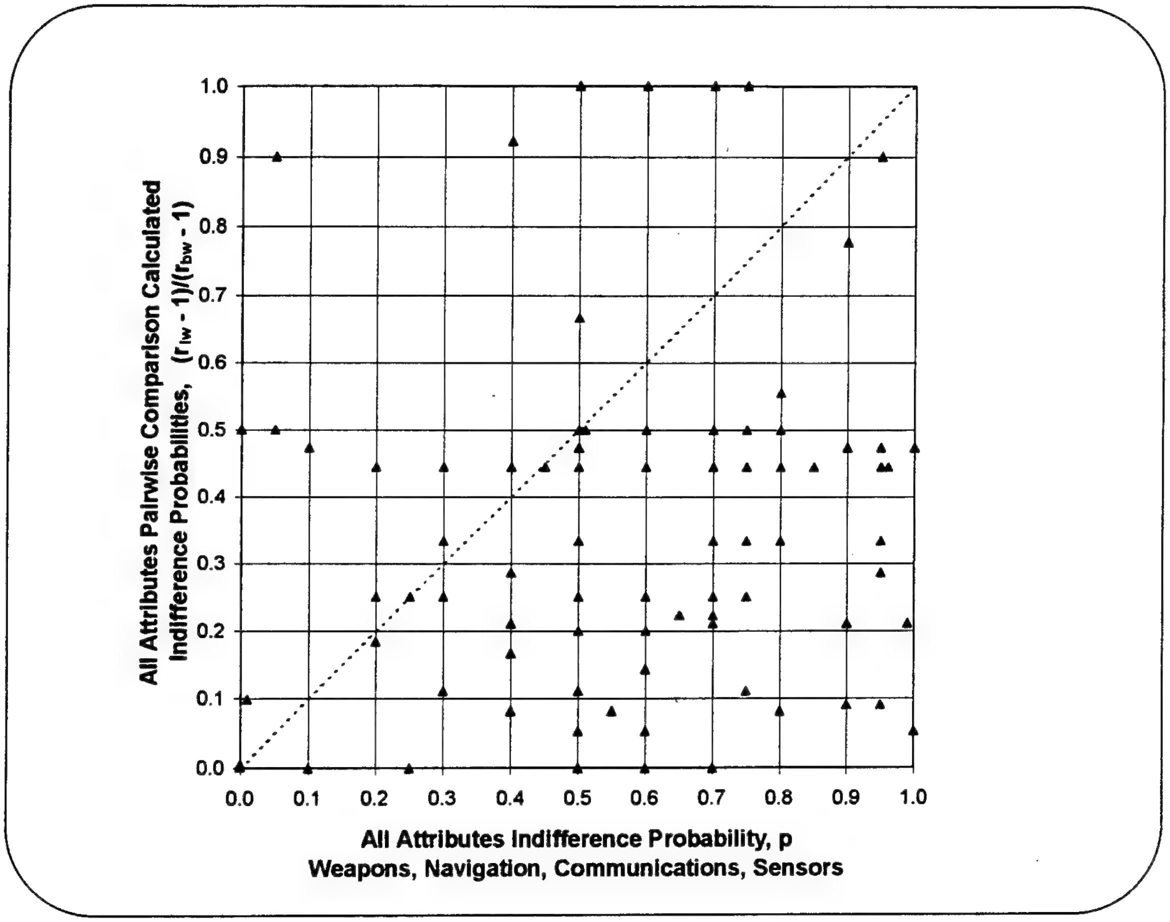


Figure 14. Inter-Method Consistency Check, Attribute Choice Pairwise Comparisons versus Indifference Probabilities, all Attributes.

## D. SUMMARY OF CONSISTENCY CHECK RESULTS

Table 2 summarizes the $d^2$, d, $d_{norm}$, $b_{norm}$, and number of data points, K, for each of the consistency checks discussed in this chapter. Table 3 summarizes the same information for the data subset consistency check graphs found in Appendix D.

| **Consistency Check** (Figure Number) | | | | | |
|---|---|---|---|---|---|
| **Intra-method Consistency Checks** | $d^2$ | d | $d_{norm}$ | $b_{norm}$ | K |
| **Method 2:** Pairwise Comparisons (10) Entire data set (w/in graph limits), all attributes | 8.9314 | 2.9885 | 0.0299 | +O.1401 | 71 |
| **Method 3:** Indifference Probabilities (11) Entire data set, all attributes | 0.0343 | 0.1851 | 0.1851 | +O.0420 | 108 |
| | | | | | |
| **Inter-method Consistency Checks** | $d^2$ | d | $d_{norm}$ | $b_{norm}$ | K |
| **Methods 1 and 2:** Marking a Linear Scale vs Pairwise Comparisons (12) Entire data set (W/in graph limits), all attributes | 12.968 | 3.601 | 0.0361 | -0.2264 | 286 |
| **Methods 1 and 3:** Marking a Linear Scale vs Indifference Probabilities (13) Entire data set, all attributes | 0.0881 | 0.2968 | 0.2968 | -0.0862 | 108 |
| **Methods 2 and 3:** Pairwise Comparisons vs Indifference Probabilities (14) Entire data set, all attributes | 0.1569 | 0.3962 | 0.3962 | -0.2052 | 103 |

Table 2. Summary Table of Consistency Check Parameters for Data Subsets Presented in Chapter IV.

| Consistency Check (Figure Number) | | | | | |
|---|---|---|---|---|---|
| **Intra-method Consistency Checks** | $d^2$ | $d$ | $d_{norm}$ | $b_{norm}$ | K |
| **Method 2: Pairwise Comparisons** Weapons (A.D-1) | 8.6406 | 2.9395 | 0.0294 | +0.1538 | 20 |
| Navigation (A.D-2) | 5.4167 | 2.3274 | 0.0233 | +0.1250 | 12 |
| Communications (A.D-3) | 5.5559 | 2.3571 | 0.0236 | +0.1132 | 17 |
| Sensors (A.D-4) | 13.216 | 3.6354 | 0.0364 | +0.0783 | 22 |
| **Method 3: Indifference Probabilities** Weapons (A.D-5) | 0.0245 | 0.1566 | 0.1566 | +0.0500 | 27 |
| Navigation (A.D-6) | 0.0484 | 0.2201 | 0.2201 | +0.0404 | 27 |
| Communications (A.D-7) | 0.0154 | 0.1240 | 0.1240 | +0.0074 | 27 |
| Sensors (A.D-8) | 0.0487 | 0.2207 | 0.2207 | +0.0704 | 27 |
| **Inter-method Consistency Checks** | $d^2$ | $d$ | $d_{norm}$ | $b_{norm}$ | K |
| **Methods 1 and 2: Marking Linear Scale vs Pairwise Comparisons** Best vs Intermediate (A.D-9) | 13.077 | 3.6162 | 0.0362 | -0.2393 | 103 |
| Best vs Worst (A.D-10) | 18.641 | 4.3176 | 0.0432 | -0.3008 | 80 |
| Intermediate vs Worst (A.D-11) | 8.0895 | 2.8442 | 0.0284 | -0.1557 | 103 |
| Weapons (A.D-12) | 9.5271 | 3.0866 | 0.0309 | -0.1687 | 76 |
| Navigation (A.D-13) | 22.787 | 4.7736 | 0.0477 | -0.3460 | 65 |
| Communications (A.D-14) | 13.341 | 3.6526 | 0.0365 | -0.2376 | 69 |
| Sensors (A.D-15) | 7.6704 | 2.7696 | 0.0277 | -0.1738 | 76 |
| **Methods 1 and 3: Marking Linear Scale vs Indifference Probabilities** Weapons (A.D-16) | 0.0759 | 0.2754 | 0.2754 | -0.1556 | 27 |
| Navigation (A.D-17) | 0.0995 | 0.3155 | 0.3155 | -0.1513 | 27 |
| Communications (A.D-18) | 0.0630 | 0.2509 | 0.2509 | -0.0299 | 27 |
| Sensors (A.D-19) | 0.1139 | 0.3375 | 0.3375 | -0.0078 | 27 |
| **Methods 2 and 3: Pairwise Comparisons vs Indifference Probabilities** Weapons (A.D-20) | 0.1316 | 0.3627 | 0.3627 | -0.2761 | 26 |
| Navigation (A.D-21) | 0.2103 | 0.4586 | 0.4586 | -0.2976 | 27 |
| Communications (A.D-22) | 0.1285 | 0.3585 | 0.3585 | -0.1305 | 25 |
| Sensors (A.D-23) | 0.0285 | 0.1689 | 0.1689 | -0.0964 | 25 |

Table 3. Summary Table of Consistency Check Parameters for Data Subsets Presented in Appendix D.

This chapter described the methods used to analyze the data, specifically intra and inter-method consistency checks. Consistency check plots and quantitative measures of consistency were presented for five main data subsets. The chapter finished with tables summarizing the consistency check parameters for 28 various data subsets.

The final chapter will interpret the consistency check parameters developed in Chapter IV for the five main data subsets.

# V. SUMMARY AND CONCLUSIONS

This chapter provides interpretations of the consistency check parameters developed in Chapter IV for the five main data subsets. Some consistency checks that yielded unexpected results are analyzed in greater detail and utility function theory applied in an attempt to explain the results. The thesis closes with discussions on applicability of the methods, experiment conclusions and suggested areas for future study.

## A. EXPERIMENT RESULTS

The following is a discussion of the experiment results. Table 4 is a reduced version of Table 2 and presents the primary consistency check parameters, the normalized dispersion parameter, $d_{norm}$ , and the normalized bias, $b_{norm}$, for the two intra-method and three inter-method consistency checks encompassing all attributes.

### 1. Intra-method Consistency Checks

#### *a. Within Method 2*

The dispersion consistency check parameter, $d_{norm}$ , for Method 2 was only 0.0299, indicating a low level of data spread within this method.

Expert responses to this method were moderately positively biased, with $b_{norm}$ = +0.1401. From the discussion in Chapter II, Subsection D.1.c, and Equation (3), we know that if the experts were perfectly consistent, then

$r_{bw} = r_{bi} r_{iw}$.

| **Consistency Check** (Figure Number) | | |
|---|---|---|
| **Intra-method Consistency Checks** | **$d_{norm}$** | **$b_{norm}$** |
| **Method 2:**<br>Pairwise Comparisons (10)<br>Entire data set (w/in graph limits), all attributes | 0.0299 | +0.1401 |
| **Method 3:**<br>Indifference Probabilities (11)<br>Entire data set, all attributes | 0.1851 | +0.0420 |
| **Inter-method Consistency Checks** | **$d_{norm}$** | **$b_{norm}$** |
| **Methods 1 and 2:**<br>Marking a Linear Scale vs Pairwise Comparisons (12)<br>Entire data set (w/in graph limits), all attributes | 0.0361 | -0.2264 |
| **Methods 1 and 3:**<br>Marking a Linear Scale vs Indifference Probabilities (13)<br>Entire data set, all attributes | 0.2968 | -0.0862 |
| **Methods 2 and 3:**<br>Pairwise Comparisons vs Indifference Probabilities (14)<br>Entire data set, all attributes | 0.3962 | -0.2052 |

Table 4. Summary of Primary Consistency Check Parameters.

A positive bias indicates that, on average, experts overestimated the derived values for $r_{bw}$ relative to the directly obtained values.

***b. Within Method 3***

Consistency check parameter magnitudes for Method 3 were the converse of those for Method 2. The $d_{norm}$ value was relatively large at 0.1851, while a nearly negligible level of bias was indicated with a $b_{norm}$ of only +0.0420. Figure 15 replots the data for Method 3 with p plotted on the horizontal axis and p - (1 - q) plotted on the vertical axis. For this plot, the horizontal axis effectively displays the line of slope 1.0 from Figure 11. This presentation confirms the consistency parameters

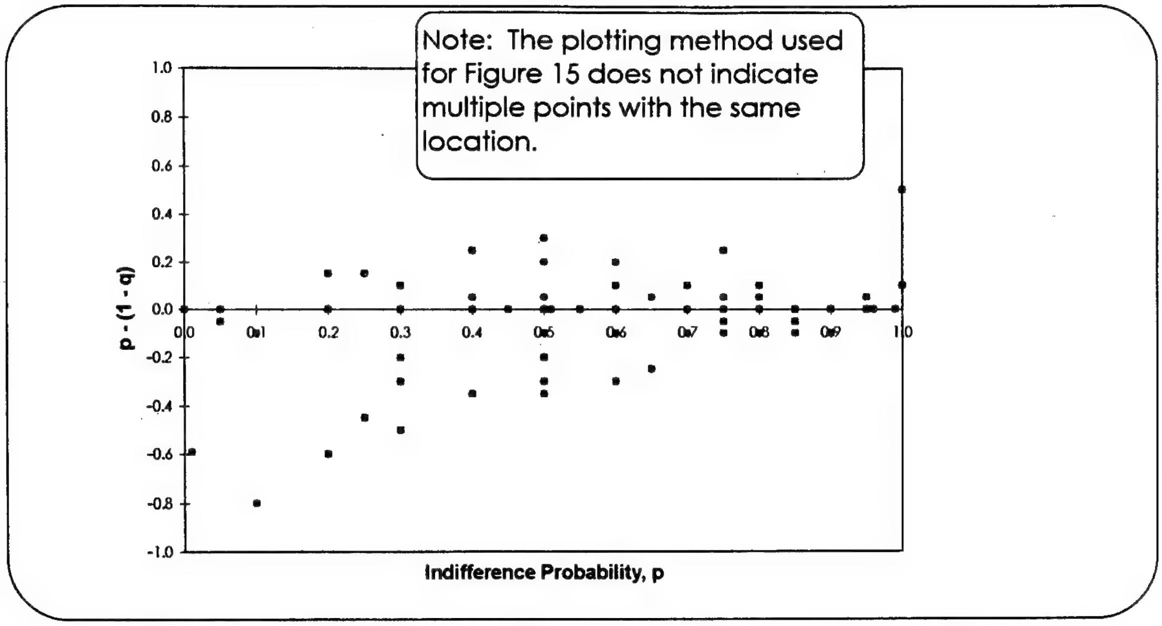


Figure 15. Alternate Intra-Method 3 Check: p - (1 - q) versus p.

analysis that the derived values for p, the (1 - q)'s, are rather widely, but fairly evenly dispersed on either side of p.

Figure 16 pictorially demonstrates Equation (6), i.e., the two decision saplings are equivalent if and only if

$$p = (1 - q), \text{ and } q = (1 - p), \text{ where } 0 \leq p, q \leq 1.$$

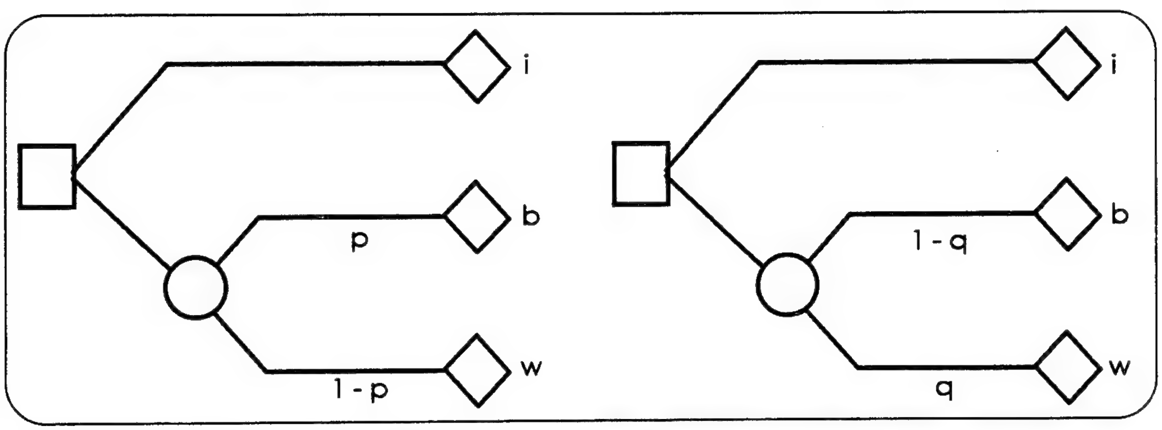


Figure 16. Two Equivalent Decision Saplings.

The parameter values indicate the experts may have had difficulty translating a corresponding value of q for a given p. This conclusion is supported by the fact that survey steps 4(a) and (b) (see Appendix B) used to collect data inputs for p and q, generated the largest number of clarification requests from the experts while they were taking the survey. A supporting interpretation of these results is that while marking a linear scale or conducting pairwise comparisons were rather natural actions for the experts, the experts were not practiced nor familiar with the concept of indifference probabilities as a tool for making comparisons. Expert training and practice with indifference probabilities might very well reduce the response dispersion for this method, improving the level of consistency.

**2. Inter-method Consistency Checks**

***a. Between Methods 1 and 2***

The $d_{norm}$ value for the check between Methods 1 and 2 was only 0.0361, indicating a relatively high level of response consistency between these two methods. The inter-method bias, however, was substantial and strongly negative, with $b_{norm}$ = (-0.2264). A negative bias indicates that, on average, the derived attribute value ratios were understated relative to the directly obtained ratios. The relatively large magnitude of the bias suggests the possibility of a systematic prejudice in the method, possibly induced by the linear scale presentation. Reviewing Equation (3), if the consistency relationship is negatively biased, then, on average

$$r_{bi} > \frac{V_b}{V_i}, \quad r_{bw} > \frac{V_b}{V_w}, \quad \text{and} \quad r_{iw} > \frac{V_i}{V_w}, \text{ where } V_{numerator} > V_{denominator} > 0.$$

Given the above, if a constant inter-Method 1 and 2 correction factor, $c_{12}$, such that $0 < c_{12} < v_{denominator}$, is *subtracted* from both $v_{numerator}$ and $v_{denominator}$; then the ratio $\left(\frac{v_{numerator}}{v_{denominator}}\right)$ increases in magnitude. Thus, there is a value of $c_{12}$ for each data point such that when subtracted from the values in both the numerator and denominator, the ratio of values equals the directly obtained ratio. The effect, then, of $c_{12}$ for a negatively biased relationship between Methods 1 and 2, is to effectively shift the origin of the linear scale to the right. For example, if $r_{bw} = 5$, $V_w = 20$ and $V_b = 60$, then

$$r_{bw} = 5 > \frac{60}{20} = 3 = \frac{V_b}{V_w}\text{ , and}$$

$$r_{bw} = 5 = \frac{V_b - c_{12}}{V_w - c_{12}} = \frac{60 - c_{12}}{20 - c_{12}} \quad \Rightarrow \quad c_{12} = 10\ .$$

Figure 17 pictorially demonstrates the effect of the $c_{12} = 10$ for the $r_{bw}$, $V_b$, and $V_w$ in the example. The strong negative bias suggests the experts had a propensity for the high end of the linear scale, and/or an aversion to the low end.

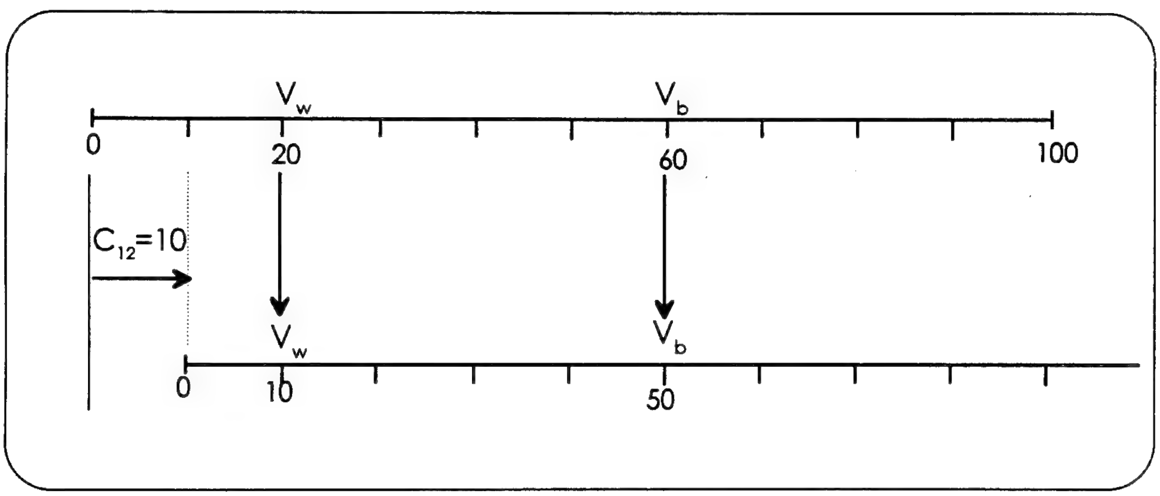


Figure 17. Pictorial Representation of Correction Factor $c_{12}$.

If $b_{norm} > 0$, then a constant $c_{12}$ is *added* to both the numerator and denominator. This effectively shifts the origin of the linear scale to the left. Application of a correction factor to the entire data subset might therefore be used to reduce systematic bias in the experts' responses due to a propensity for either end of the linear scale.

Finding a globally optimal value of $c_{12}$ directly is difficult because of the existence of local minima and maxima. Heuristic and iterative approaches to find a near optimal $c_{12}$, however, are relatively easy to perform. To test the concept of a correction factor, integer valued $c_{12}$'s from one to ten were iteratively applied to the experimental data and the effects on $b_{norm}$ noted. The magnitude of $b_{norm}$ was reduced from an uncorrected value of (-0.2264), to a negligible value of 0.0241 when $c_{12} = 9$, a tenfold improvement.

***b. Between Methods 1 and 3***

The value of $d_{norm}$ for the check between Methods 1 and 3 was 0.2968, which seems to indicate a low level of response consistency between these two methods. The modest $b_{norm}$ of (-0.0862) was the smallest level of bias of the three inter-method consistency checks. To investigate the high value of $d_{norm}$ further, Figure 18 replots the data for this inter-method check with p plotted on horizontal axis, and $p - \frac{(V_i - V_w)}{(V_b - V_w)}$ plotted on the vertical axis. As with the Method 3 intra-method consistency check, this presentation confirms the consistency parameters analysis that the derived values for p are widely, but fairly evenly dispersed on either side of p. An interesting and unanticipated phenomenon also surfaced in Figure 18. The bias, which is the derived minus the directly obtained indifference probability, appears to become

more negative with increasing p. This data behavior warranted closer examination to search for an explanation.

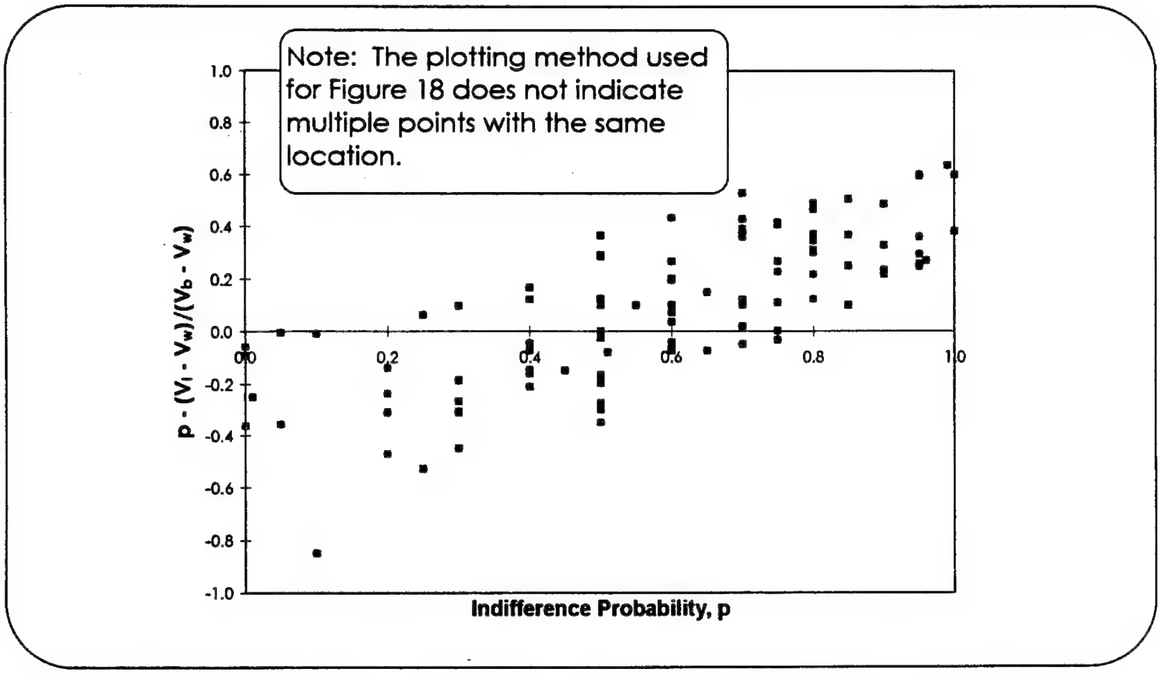


Figure 18. Alternate Inter-Methods 1 and 3 Check: $p - [(V_i - V_w)/(V_b - V_w)]$ versus p.

From Equation (7), if the experts were perfectly consistent, then $p = \left(\frac{V_i - V_w}{V_b - V_w}\right)$ over the entire range of p and all the data points would lie on the horizontal axis. However, in Figure 18 it is evident that on average,

$$\text{if} \quad p > 0.5, \quad \text{then} \quad p > \left(\frac{V_i - V_w}{V_b - V_w}\right), \tag{12}$$

$$\text{if} \quad p < 0.5, \quad \text{then} \quad p < \left(\frac{V_i - V_w}{V_b - V_w}\right), \quad \text{and} \tag{13}$$

$$\text{if} \quad p \cong 0.5, \quad \text{then} \quad p \cong \left(\frac{V_i - V_w}{V_b - V_w}\right). \tag{14}$$

Apparently there is a behavioral phenomenon that caused the experts to respond inconsistently.

Consider the left decision sapling in Figure 16, except this time the result node outcomes are measured by option utility values, U(i), U(b), and U(w), instead of the options themselves, for the intermediate, best, and worst option utility values from top-to-bottom, respectively. Modifying Equation (4) by substituting $V_i$, $V_b$, and $V_w$ with U(i), U(b), and U(w), respectively, we get

$$U(i) = pU(b) + (1 - p)U(w), \quad \text{thus}$$

$$p = \left(\frac{U(i)-U(w)}{U(b)-U(w)}\right). \tag{15}$$

The relationship between Equations (12) and (15) then is

$$\left(\frac{U(i)-U(w)}{U(b)-U(w)}\right) = p > \left(\frac{V_i-V_w}{V_b-V_w}\right). \tag{16}$$

The relationship between Equations (13) and (15) then is

$$\left(\frac{U(i)-U(w)}{U(b)-U(w)}\right) = p < \left(\frac{V_i-V_w}{V_b-V_w}\right). \tag{17}$$

Figure 19 plots both a risk neutral utility function (line AB) and a generic risk averse utility function (curve CD). Let $V_w$, $V_i$, and $V_b$, plotted on the X-coordinate, be the values of the worst, intermediate, and best options, respectively. Let U(w), U(i), and U(b) be the utility values from the

risk averse utility function corresponding to the worst, intermediate, and best options, respectfully. Note that

for all $V_i$ such that $V_w < V_i < V_b$, then

$$\left(\frac{U(i)-U(w)}{U(b)-U(w)}\right) = p > \left(\frac{V_i-V_w}{V_b-V_w}\right). \qquad (18)$$

Therefore, a person whose data values of p, $V_w$, $V_i$, and $V_b$ support Equation (18) is displaying risk averse behavior.

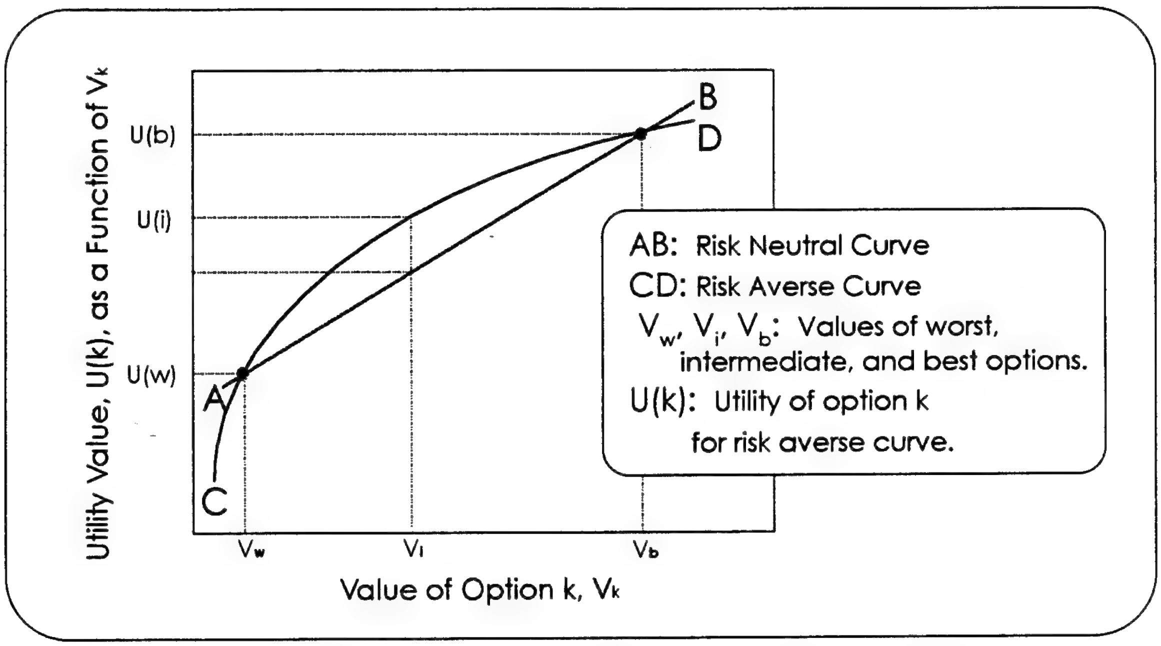


Figure 19. Plot of Risk Neutral and Risk Averse Utility Function Curves.

Similarly, if the utility function curve is convex, the inequality in Equation (18) reverses and

$$\left(\frac{U(i)-U(w)}{U(b)-U(w)}\right) = p < \left(\frac{V_i-V_w}{V_b-V_w}\right), \qquad (19)$$

implying that data satisfying Equation (19) indicates the person is displaying risk prone behavior.

From Equation (14),

$$p \cong \left(\frac{V_i - V_w}{V_b - V_w}\right) \cong 0.5,$$

$$V_i - V_w \cong 0.5(V_b - V_w)$$

$$2(V_i - V_w) \cong V_b - V_w$$

$$2V_i \cong V_b + V_w,$$

$$V_i \cong \left(\frac{V_b + V_w}{2}\right). \tag{20}$$

Similarly, from Equation (13), for $p < 0.5$,

$$V_i > pV_b + (1-p)V_w, \quad \text{and} \tag{21}$$

from Equation (12), for $p > 0.5$,

$$V_i < pV_b + (1-p)V_w. \tag{22}$$

The risk neutral, risk prone, and risk averse regions of Figure 18 are those that satisfy Equations (20), (21), and (22), respectively. Figure 20 displays the non-neutral regions pictorially. The experts, therefore, are risk averse when p is large, risk neutral when $p \cong 0.5$, and risk prone when p is small.

Equations (20) through (22) also make intuitive sense. Figure 21 shows a linear scale with $V_w$ and $V_b$ marked towards either end, and the risk prone, neutral, and averse regions labeled. If $V_i$ is at point 1, the intermediate option's value is not that much greater than that of the

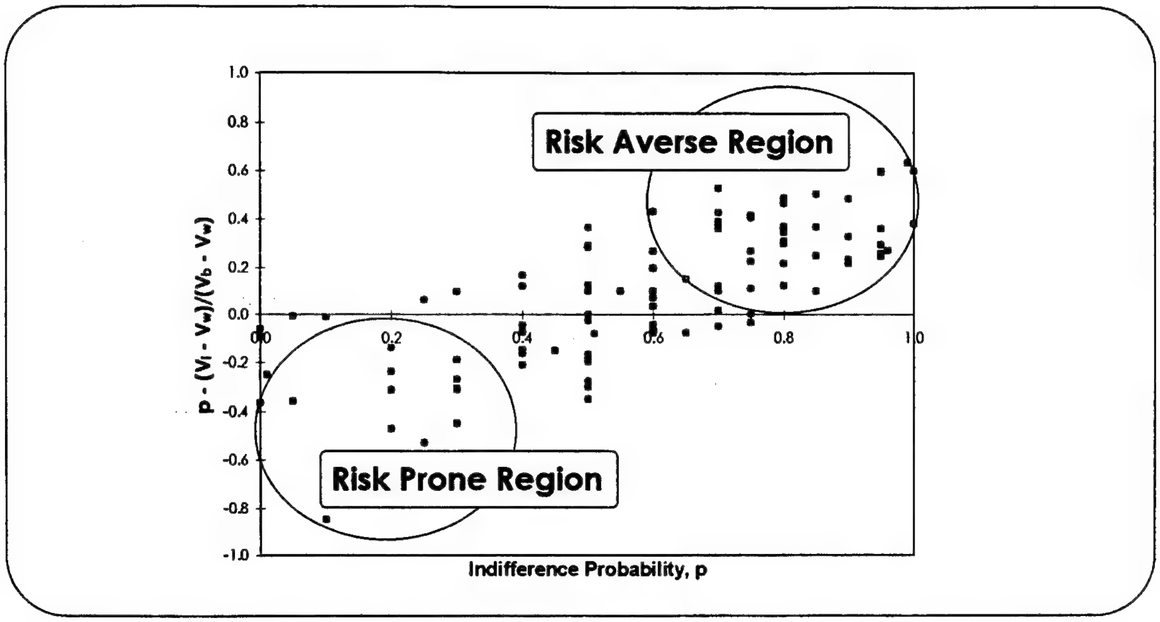


Figure 20. Risk Prone and Risk Averse Regions of Figure 18.

worst option, and the expert is willing to accept a p that results in a negative expected value for a gamble between the best and worst options, rather than accept the intermediate option for certain. Conversely, if $V_i$ is at point 2, the intermediate option's value is almost as great as the best option's value, and the expert must have a p large enough to produce a positive expected value in the gamble.

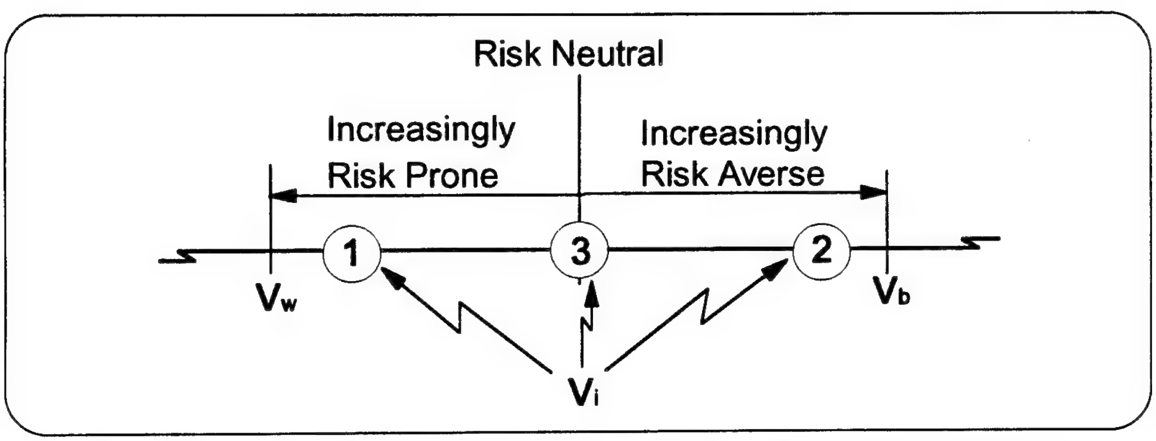


Figure 21. Linear Scale Risk Prone, Neutral, and Averse Regions.

In summary, the plot in Figure 18 displays a distinctive pattern that was not anticipated. Analyzing the plot reveals that the experts were risk prone when $V_i$ was closer to $V_w$ than $V_b$, and risk averse when $V_i$ was closer to $V_b$ than $V_w$.

### c. *Between Methods 2 and 3*

The inter-method consistency check between Methods 2 and 3 displayed the same gross parameter behavior as with the preceding check. The value of $d_{norm}$ for this check, the largest of the five main data subsets, was 0.3962, which appears to indicate a very low level of response consistency between these two methods. The inter-method bias was strongly negative at (-0.2052). Figure 22 replots the data for this inter-method check with p plotted on the horizontal axis, and $p-\frac{(r_{iw}-1)}{(r_{bw}-1)}$ plotted on the vertical axis.

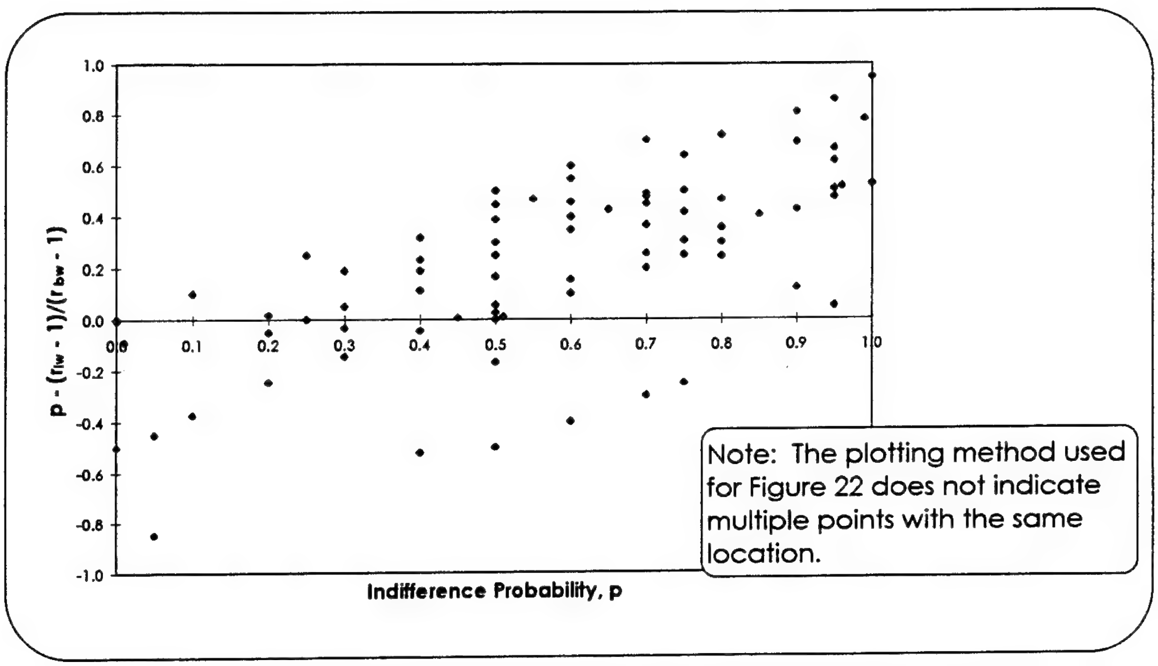


Figure 22. Alternate Inter-Methods 2 and 3 Check: $p - [(r_{iw} - 1)/(r_{bw} - 1)]$ versus p.

As with the inter-method consistency check between Methods 1 and 3, this check also displayed the curious behavior of the bias seemingly becoming more negative with increasing p. Similar arguments can be made to show that, on average, the experts were risk prone, neutral, and averse when $p < 0.5$, $p \cong 0.5$, and $p > 0.5$, respectively.

## B. METHOD APPLICABILITY

Analysts using the methods described in and employed to conduct an experiment for this thesis could find applicability in numerous qualitative situations. The methods are not substitutes for thorough cost-benefit or similar analyses. However, in situations where there is a readily available pool of subject matter experts, but not an available, affordable, or computationally logical data base, these methods show definite applicability for developing a quantifiable and comparable measure of value, preference, worth, etc.

Given several decision alternative sets, whether they are tanks, bicycles, or televisions, one could relatively quickly dissect the alternative sets into attributes and attribute choices. The survey question formats exercised for this thesis could then be adapted for the particular alternative sets under evaluation.

## C. EXPERIMENT CONCLUSIONS

The procedures used in this thesis can be employed to quantitatively evaluate attribute choices with no natural measurement basis, the first major step in evaluating multi-attribute decision alternatives.

The intra-method consistency checks of the experimental data showed that the pairwise comparison method (Method 2) yielded notably

smaller dispersion parameters than the indifference probability method (Method 3). Method 2 responses, however, were much more biased than those of Method 3. These general observations imply there may be possible tradeoffs available between dispersion and bias between Methods 2 and 3. Consistency parameters for checks between methods were generally greater than the intra-method parameters.

The most interesting observation borne out by variants of the consistency checks was not anticipated before conducting the checks. This was the incontestable relationship between expert response behavior and attribute choice and indifference probability values. The experts displayed risk prone behavior when they perceived there was little to loose and much to gain. Conversely, the experts displayed risk averse behavior when they perceived there was much to loose and little to gain.

## D. AREAS FOR FUTURE STUDY

A considerable amount of time spent on this thesis was devoted to identifying the experiment subject matter, approach, and procedures, and survey development, trial testing, and modification. The time devoted to experimental approach and survey development preempted the thorough discussion and consistency analysis of attribute weighting factors. The first and foremost area of future study would be to develop the discussion and analysis of attribute weighting factors, analyze the remaining data in Appendix C, and develop actual alternative set values.

# APPENDIX A. ATTRIBUTE, ATTRIBUTE CHOICE, AND MULTI-ATTRIBUTE DECISION ALTERNATIVE SET NOMENCLATURE AND INDEXING

This appendix provides a detailed explanation of the nomenclature and indexing system used throughout this thesis. Equation (1) [see Chapter II, Section B] is presented below as a springboard for the following discussion:

$$V(j) = \sum_{i=1}^{n} \alpha_i V_i(j) \quad \text{for any } j = 1, 2, \ldots, m, \qquad \text{where} \tag{1}$$

$V(j)$ = overall value for alternative set j;

$\alpha_i$ = weighting factor for attribute i; $\alpha_i$ is the amount of set j's overall value obtained from a unit of attribute i;

$\alpha_i > 0$ if, for attribute i, bigger is better [Ref. 1, Table 7.2]; and,

$\alpha_i < 0$ if, for attribute i, smaller is better; and,

$V_i(j)$ = value of attribute i for alternative set j.

**DEFINITIONS:**

•**Multi-Attribute Decision Alternative Set:** Also called a *decision alternative, alternative set*, or *set*, a multi-attribute decision alternative set is a complex object upon which a decision maker wants to place a quantitative value in order to directly compare it with similar complex objects. For example, an auto dealership may present a perspective car buyer (i.e., a decision maker) with dozens of alternative sets (i.e., cars) that he wants to evaluate.

•**Attribute:** An *attribute* is an alternative set *characteristic* common to all (or at least most) of the sets considered for evaluation and ranking. For example, attribute candidates for new cars could include gas

mileage and exterior color. Note that some attributes (e.g., gas mileage) are much easier to quantify than others (exterior color).

•**Attribute Choice:** An *attribute choice*, or *choice*, is the particular item or characteristic of a certain attribute in each alternative set. For the car example, attribute choices for the exterior color attribute may be green, red, and black for some car models, and silver, dark blue, red, and turquoise for others. The gas mileage attribute choice for one model of car might be 17.9 miles per gallon (mpg) and 24.1 mpg for a different model. Note that the number of attribute choices need not be the same for each attribute (six exterior color attribute choices, but only two gas mileage choices). And that not all alternative sets may be available or feasible (the dealer may not have a red car that gets 24.1 mpg).

Table A.1 below demonstrates the architecture between *attribute categories* and *attribute choices*.

**Attribute**, indexed by i. For example:
-speed (1), range (2), esthetics (3), ...., maintainability (n)

Each Attribute need not have the same number of Attribute Choices.

The Attribute index, i, is only for notational convenience. There is no ranking or value associated with i. When the letter i is used as a subscript for the letters r or V, the i *does* imply an *intermediate* ranking.

| Intra-Attribute Attribute Choice Ranking, k | | Attribute, i | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | ••• | n |
| (Most preferred level of Attribute i) | 1 | $v_1$ | $v_2$ | $v_3$ | ••• | $v_n$ |
| (Second Most preferred level of Attribute i) | 2 | $w_1$ | $w_2$ | $w_3$ | ••• | $w_n$ |
| (Third Most preferred level of Attribute i) | 3 | $x_1$ | $x_2$ | $x_3$ | ••• | $x_n$ |
| | ••• | ••• | ••• | ••• | ••• | ••• |
| (Least preferred level of Attribute i) | $K_i$ | $z_1$ | $z_2$ | $z_3$ | ••• | $z_n$ |

Table A.1. Attribute and Attribute Choice Definitions

**Attribute Choices** (<u>within Attribute i</u>), indexed by k and ranked in order from the Attribute Choice with the most preferred level of Attribute i ($v_i$ in the table) to the Attribute Choice with the least preferred level of Attribute i ($z_i$ in the table).

Again, there need *not* be the same number of Attribute Choices for each Attribute. $K_i$ is the number of Attribute Choices in Attribute i.

Table A.2 below demonstrates the architecture between *attributes* and *multi-attribute decision alternative sets.*

**Attribute**, indexed by i. For example:
-speed (1), range (2), esthetics (3), ...., maintainability (n)

Each Attribute need not have the same number of Attribute Choices.

The Attribute index, i, is only for notational convenience. There is no ranking or value associated with i. When the letter i is used as a subscript for the letters r or V, the i *does* imply an *intermediate* ranking.

| Multi-Attribute Decision Alternative Sets, j (Note: The ordering of the alternative sets is arbitrary. The text below describes a suggested possible method of ordering the sets.) | | Attribute, i | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | ••• | n |
| Multi-Attribute Decision Alternative Set , j = 1. Set 1 contains the *most preferred Attribute Choice* from *each Attribute* (**IF** the set is feasible) (In the table, $j = v_1, v_2, v_3, ...., v_n$) | 1 | $v_1$ | $v_2$ | $v_3$ | ••• | $v_n$ |
| Multi-Attribute Decision Alternative Set , j = 2. Set 2 contains the most preferred Attribute Choice from each Attribute except Attribute n (**IF** the set is feasible). The set j = 2 Attribute n element is the second most preferred Attribute Choice from Attribute n. | 2 | $v_1$ | $v_2$ | $v_3$ | ••• | $w_n$ |
| Multi-Attribute Decision Alternative Set , j = 3. Set 3 contains the most preferred Attribute Choice from each Attribute except Attribute n (**IF** the set is feasible). The set j = 3 Attribute n element is the third most preferred Attribute Choice from Attribute n. | 3 | $v_1$ | $v_2$ | $v_3$ | ••• | $x_n$ |
| Subsequent Multi-Attribute Decision Alternative Sets , j = 4, 5, ..., m -1, continue in a fashion similar to the Arabic numbering system (where Attribute n equates to the one's column, Attribute n-1 the ten's column, etc.) | ••• | ••• | ••• | ••• | | |
| Multi-Attribute Decision Alternative Set , j = m. Set m contains the *least preferred Attribute Choice* from *each Attribute* (**IF** the set is feasible) (In the table, $j = z_1, z_2, z_3, ...., z_n$) | m | $z_1$ | $z_2$ | $z_3$ | ••• | $z_n$ |

Table A.2. Attribute and Multi-Attribute Decision Alternative Sets Definitions

**Multi-Attribute Decision Alternative Sets** contain a single Attribute Choice from each Attribute. The sets are indexed by j. Sets are ordered in some logical fashion. For example: set j = 1 contains the Attribute Choices with the most preferred level of their respective Attribute (**IF** it is a feasible set!), while the set, j = m, contains the Attribute Choices with the least preferred level of their respective Attribute (**IF** it is a feasible set!). A quasi Arabic numbering system, where Attribute n is the *one's* column, Attribute n-1 is the *ten's* column, etc., is the recommended ordering system.

## APPENDIX B. LAMPS DECISION ALTERNATIVES SURVEY GUIDE AND RESPONSE FORM

# LAMPS Decision Alternatives Survey

**Overview:** This survey is being conducted to collect thesis data. The data will be used to statistically analyze methods for assessing and ranking decision alternatives that have no natural basis for comparison. You, the "Decision Maker", will be presented with a series of decision problems involving LAMPS (Light Airborne Multipurpose System) helicopter systems and invited to give both subjective and quantitative responses.

**Scenario:** All the following questions should be considered in context with the overall mission of USW (Undersea Warfare); redetection phase all the way through to battle damage assessment (BDA).

**Step 1: Subjective Rankings:** You will be presented with sets of three helicopter systems in each of four categories: *Weapons, Navigation, Communications*, and *Sensors*. **Always keeping in mind the given scenario (i.e., a complete USW mission),** you are to rank the three helicopter systems in each category from best to worst. Below is a non-LAMPS example:

- Example:
  - **Scenario**: You receive your current salary and are out shopping for a birthday gift for your wife or girlfriend.
  - **"System Options"**:
    - $5 gift
    - $20 gift
    - $100 gift
  - Most people would probably rank the "system options" for the given scenario as follows:
    - $5 gift • 3
    - $20 gift • 2
    - $100 gift • 1

Do you understand the task? Do you have any questions? ☐ Page 1 of response form.

☐ • • • • • • • • • • • •

**<u>Step 2(a): Quantitative Assessment:</u>** Now that you have ranked the three helicopter system alternatives in each category, you will be asked to give your opinion on the *relative value* of *how much better* the *system* you ranked "best" is over the "intermediate" and "worst" systems, and *how much better* the "intermediate" system is over the "worst" system, **always keeping in mind that your responses should be in context with performing the given scenario of a complete USW mission.**

- Simplified example:
  - **Scenario**: You receive your current salary and are out shopping for a birthday gift for your wife or girlfriend. Same "system options" as before:

- The (Best) $100 bill is 5 times *better* than the (Intermediate) $20 bill.
- The (Best) $100 gift is 3 times *better* than the (Intermediate) $20 gift.

- The (Best) $100 bill is 20 times *better* than the (Worst) $5 bill.
- The (Best) $100 gift is 8 times *better* than the (Worst) $5 gift.

- The (Intermediate) $20 bill is 4 times *better* than the (Worst) $5 bill.
- The (Intermediate) $20 gift is 2.5 times *better* than the (Worst) $5 gift.

Do you understand the task? Do you have any questions? ☐ Page 2 of response form.

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**Step 2(b): Quantitative Assessment (cont.):** The following set of questions asks your opinions on the *relative value* of *how much worse* the "worst" system is compared to the "best" and "intermediate" systems, and *how much worse* the "intermediate" system is compared to the "best" system. **Again, always keep in mind that your responses should be in context with performing the given mission scenario.**

- Simplified example:
  - **Scenario**: You receive your current salary and are out shopping for a birthday gift for your wife or girlfriend. Same "hardware options" as before:

- The (Worst) $5 bill is 20 times *worse* than the (Best) $100 bill.
- The (Worst) $5 gift is 8 times *worse* than the (Best) $100 gift.

- The (Worst) $5 bill is 4 times *worse* than the (Intermediate) $20 bill.
- The (Worst) $5 gift is 2.5 times *worse* than the (Intermediate) $20 gift.

- The (Intermediate) $20 bill is 5 times *worse* than the (Best) $100 bill.
- The (Intermediate) $20 gift is 3 times *worse* than the (Best) $100 gift.

Do you understand the task? Do you have any questions? ☐ Page 3 of response form.

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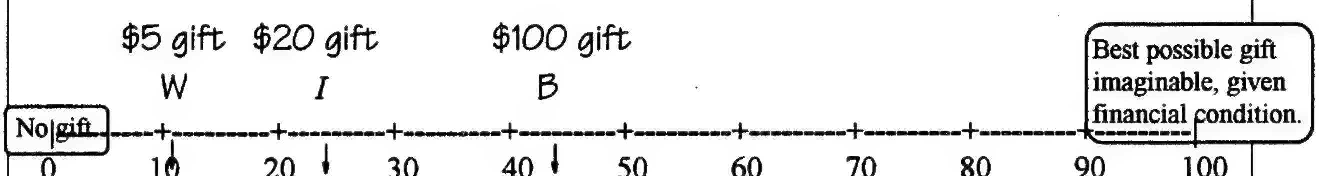
**Step 3: Marking a Linear Scale:** You will now be presented with a line labeled at one end with a zero (0) and the other end with a 100. *If zero represents an absolutely worthless helicopter system* **for the given scenario**, *and 100 represents the absolute best helicopter system imaginable* **for the given scenario**, mark the line where you think the "best" (B), "intermediate" (I), and "worst" (W) systems, as ranked earlier, would fall on the line.

- Simplified example:
  - **Scenario**: You receive your current salary and are out shopping for a birthday gift for your wife or girlfriend. Same "system options" as before:




Do you understand the task? Do you have any questions? ☐ Page 4 of response form.

☐ • • • • • • • • • • • •

**<u>Step 4(a): Let's Make a Deal!:</u>** You are outfitted with the system you have ranked as "intermediate". It is yours to employ **in the given scenario**. However, you have the option to trade in your current (intermediate) system for a <u>chance</u> at getting the "best" system. If you take the gamble and win, you get the "best" system. If you take the gamble and lose, you get the "worst" system. If you do not take the gamble, you keep the "intermediate" system. *What is the* ***<u>minimum</u> percentage chance of winning the "best" system*** *you are willing to accept in order to take the gamble?*

•Simplified example:

•**Scenario**: You are a college football coach. There are three seconds left in the last game of the regular season. Your team just scored a touchdown and is currently down by one point. Your "system options" are the following:

•"Worst": Do not convert on the extra point attempt, either kick or two-point attempt, and loose the game.
•"Intermediate": Kick the extra point to tie the game.
•"Best": Score a two-point conversion to win the game

•Now, *if you are guaranteed able to tie the game* (your team has an outstanding kicker, he *never* misses), what is the ***<u>minimum</u> percentage chance of getting the "best" result*** (i.e., winning the game) you are willing to accept in order to take the gamble and possibly end up with the "worst" result (i.e., loosing the game)?

•Your minimum acceptable percentage chance of getting the "best" result would most likely depend on such factors as your win-lose record, post-season bowl game opportunities, or chances of winning the league or national title, etc. For example:

•If tying the game meant holding on to the league championship and a bowl game appearance, while loosing the game would terminate your season, the minimum percentage chance of getting the "best" result (i.e., winning the game) would probably have to be very high (close to 100 percent) in order to take the gamble.

•On the other hand, if the only way your team could get a bowl game appearance was to win the game outright, you would probably be willing to take a big gamble, risk the guaranteed tie, and accept a rather low minimum percentage chance (close to zero percent) of getting the "best" result (winning the game).

•The previous examples are probably the extremes. Depending on the consequences of a win, tie, or lose (e.g., school pride, coaches job, etc.), *your* minimum acceptable percentage chance of risking the guaranteed "intermediate" result for a chance at getting the "best" result would likely fall somewhere in between.

For the actual survey questions, you will be asked to provide a percent figure (from 0-100, inclusive). **Remember to keep in mind the scenario, a complete USW mission.**

Do you understand the task? Do you have any questions? ☐ Page 5 of response form.
☐ • • • • • • • • • • • •

**<u>Step 4(b): Let's Make a Deal! (Again!):</u>** Just as with the previous task, you are outfitted with the system you have ranked as "intermediate". It is yours to employ **in the given scenario**. However, you have the option to trade in your current (intermediate) system for a <u>chance</u> at getting the "best" system. If you take the gamble and win, you get the "best" system. If you take the gamble and lose, you get the "worst" system. If you do not take the gamble, you keep the "intermediate" system. *What is the **<u>maximum</u> percentage chance of getting the "worst" system** you are willing to accept in order to take the gamble?*

•Simplified example:

•**Scenario**: Same sample scenario as before... You are a college football coach. There are three seconds left in the last regular game of the season. Your team just scored a touchdown and is currently down by one point. Your "system options" are the following:

•"Worst": Do not convert on the extra point attempt, either kick or two-point attempt, and loose the game.

•"Intermediate": Kick the extra point to tie the game.

•"Best": Score a two-point conversion to win the game

•Now, *if you are guaranteed able to tie the game* (your team has an outstanding kicker, he *never* misses), what is the ***<u>maximum</u> percentage chance of getting the "worst" result*** (i.e., loosing the game) you are willing to accept in order risk the guaranteed tie gambling for the win?

•As with the previous task, your maximum acceptable percentage chance of getting the "worst" result would most likely depend on such factors as your win-lose record, post-season bowl game opportunities, or chances of winning the league or national title, etc. For example:

•If tying the game meant holding on to the league championship and a bowl game appearance, while loosing the game would terminate your season, the maximum percentage chance of getting the "worst" result (i.e., loosing the game) would probably have to be very small (close to zero percent) in order to take the gamble.

•On the other hand, if the only way your team could get a bowl game appearance was to win the game outright, you would probably be willing to take a big gamble, risk the guaranteed tie, and accept a rather high maximum percentage chance (close to 100 percent) of getting the "worst" result (i.e., loosing the game).

•The previous examples are probably the extremes. Depending on the consequences of a win, tie, or lose (e.g., school pride, coaches job security, etc.), *your* maximum acceptable percentage chance of risking the guaranteed "intermediate" result gambling for the "best" result would likely fall somewhere in between.

For the actual survey questions, you will be asked to provide a percent figure (from 0-100, inclusive) . **Remember to keep in mind the scenario, a complete USW mission.**

Do you understand the task? Do you have any questions? ☐ Page 6 of response form.

☐ • • • • • • • • • • • •

**<u>Note:</u>** This final part of the survey should only take a few moments. You will be presented with a short series of questions soliciting your inputs on the *relative* importance of the four *categories* of systems presented earlier; namely *Weapons, Communications, Navigation,* and *Sensors*. **The underlying scenario remains unchanged; a complete USW mission from the redetection phase all the way through BDA.**

Of course, all four systems categories are vital to complete a successful USW mission. These last few questions hope to canvass your expert opinion as to the relative importance of each.

☐ • • • • • • • • • • • •

**<u>Step 5: Subjective Rankings</u>:** The four helicopter systems categories, *Weapons, Navigation, Communications*, and *Sensors,* are to be ranked from *most important* (or *valuable*) to *least important* (or *valuable*) **with respect to the given mission scenario (i.e., a complete USW mission).**

| | |
|---|---|
| Weapons | • ________ |
| Navigation | • ________ |
| Communications | • ________ |
| Sensors | • ________ |

Do you understand the task? Do you have any questions? ☐ Page 7 of response form.

☐ • • • • • • • • • • • •

**<u>Step 6: Pairwise Comparisons:</u>** You will now be asked to give your opinions on the *relative value* (or *importance*) **to the given mission scenario (i.e., a complete USW mission)** of the four systems categories, *compared two at a time.* Your answers will be placed in a partial matrix. Entries in the matrix will be numerical values of *how much more important* (or *valuable*) the *row* system category is relative to the *column* system category. For example, if the row system category is 10 times more valuable (important) for the USW mission than the column system category, you would enter a 10. If, on the other hand, the column category was three times more important than the row category, you would enter 1/3.

| | (2) [ ] | (3) [ ] | (4) [ ] |
|---|---|---|---|
| (1) [ ] | | | |
| (2) [ ] | | | |
| (3) [ ] | | | |

Do you understand the task?

Do you have any questions?

☐ Page 7 of response form.

☐ • • • • • • • • • • • •

**<u>Step 7: Unlimited Budget:</u>** You are now outfitted with the systems you ranked as "worst" during the first part of the survey for all four of the system categories. If you were provided a budget that allowed you improve the systems from "worst" to "best" in all four categories, what proportion (percentage) of the budget would you allocate *to each category*? **(Keep in mind the given scenario, i.e., a complete USW mission.)**

| | |
|---|---|
| Weapons | |
| Navigation | |
| Communications | |
| Sensors | |
| TOTAL | 100 |

Do you understand the task? Do you have any questions? ☐ Page 7 of response form.

☐ • • • • • • • • • • • •

**<u>Step 8: Let's *Really* Make a Deal!:</u>** You are outfitted with the "best" system in one system category, and the "worst" systems in the remaining three system categories. This system suite is yours to employ **in the given scenario (complete USW mission).** However, you have the option to trade in your current (one "best" and three "worsts") suite for a <u>chance</u> at getting the "best" systems in ***all four*** system categories. If you take the gamble and win, you get the "best" systems in all four system categories. The downside is, if you take the gamble and lose, you get the "worst" systems in all four categories. If you do not take the gamble, you keep the system suite you have been given (one "best" and three "worsts"). *What is the **<u>min</u>imum percentage chance of winning the "best" systems in all four system categories** you are willing to accept in order to take the gamble?*

| | Weapon | Nav | Comms | Sensors |
|---|---|---|---|---|
| Given System Suite.. | | | | |
| Win Gamble............ | | | | |
| Lose Gamble........... | | | | |

•Minimum percentage chance of winning in order to take gamble:

Do you understand the task? Do you have any questions? ☐ Page 8 of response form.

☐ • • • • • • • • • • • •

**<u>Step 9: Decision Maker Background Information:</u>** Please answer the background information questions listed on page 9 of the response form. This data will be analyzed for any discernible patterns or trends.

## Response Form

**Step 1: Subjective Rankings:** Rank the following sets of helicopter systems from best (1) to worst (3). **(Again, keep in mind the given scenario, i.e., a complete USW mission.)**

**•Weapons:**
- •Mk-46 Torpedo (Mk-46), • ____________
- •Conventional 500# Depth Charge (500#), • ____________
- •Mk-50 Torpedo (Mk-50). • ____________

**•Navigation:**
- •Global Positioning System (GPS), • ____________
- •TACAN (TACAN), • ____________
- •Doppler Radar (Dop). • ____________

**•Communications:**
- •Datalink (D/L), • ____________
- •Satellite Communications (Sat Com), • ____________
- •UHF/VHF Radio (Radio). • ____________

**•Sensors:**
- •Magnetic Anomaly Detector (MAD), • ____________
- •Surface Search Radar (Radar), • ____________
- •Forward Looking Infrared (FLIR). • ____________

**<u>Step 2(a): Quantitative Assessment:</u>** Give your quantitative opinions on how much *better* the "best" system is over the "intermediate" and "worst" systems, and how much *better* the "intermediate" system is over the "worst". **(Again, keep in mind the given scenario, i.e., a complete USW mission.)**

☐ • • • • • • • • • • • •

•**Weapons:** Best:__________ Intermediate: __________ Worst:__________

•The (Best) __________ is ____ times *better* than the (Intermediate) __________.

•The (Best) __________ is ____ times *better* than the (Worst) __________.

•The (Intermediate) __________ is ____ times *better* than the (Worst) __________.

•**Navigation:** Best:__________ Intermediate: __________ Worst:__________

•The (Best) __________ is ____ times *better* than the (Intermediate) __________.

•The (Best) __________ is ____ times *better* than the (Worst) __________.

•The (Intermediate) __________ is ____ times *better* than the (Worst) __________.

•**Communications:** Best:__________ Intermediate: __________ Worst:__________

•The (Best) __________ is ____ times *better* than the (Intermediate) __________.

•The (Best) __________ is ____ times *better* than the (Worst) __________.

•The (Intermediate) __________ is ____ times *better* than the (Worst) __________.

•**Sensors:** Best:__________ Intermediate: __________ Worst:__________

•The (Best) __________ is ____ times *better* than the (Intermediate) __________.

•The (Best) __________ is ____ times *better* than the (Worst) __________.

•The (Intermediate) __________ is ____ times *better* than the (Worst) __________.

☐ • • • • • • • • • • • •

**<u>Step 2(b): Quantitative Assessment (cont.):</u>** Give your quantitative opinions on how much *worse* the "worst" system is than the "best" and "intermediate" systems, and how much *worse* the "intermediate" system is than the "best". **(Again, keep in mind the given scenario, i.e., a complete USW mission.)**

- **Weapons:** Best:__________ Intermediate: __________ Worst:__________
  - The (Worst) __________ is ____ times *worse* than the (Best) __________.
  - The (Worst) __________ is ____ times *worse* than the (Intermediate) __________.
  - The (Intermediate) __________ is ____ times *worse* than the (Best) __________.

- **Navigation:** Best:__________ Intermediate: __________ Worst:__________
  - The (Worst) __________ is ____ times *worse* than the (Best) __________.
  - The (Worst) __________ is ____ times *worse* than the (Intermediate) __________.
  - The (Intermediate) __________ is ____ times *worse* than the (Best) __________.

- **Communications:** Best:__________ Intermediate: __________ Worst:__________
  - The (Worst) __________ is ____ times *worse* than the (Best) __________.
  - The (Worst) __________ is ____ times *worse* than the (Intermediate) __________.
  - The (Intermediate) __________ is ____ times *worse* than the (Best) __________.

- **Sensors:** Best:__________ Intermediate: __________ Worst:__________
  - The (Worst) __________ is ____ times *worse* than the (Best) __________.
  - The (Worst) __________ is ____ times *worse* than the (Intermediate) __________.
  - The (Intermediate) __________ is ____ times *worse* than the (Best) __________.

**<u>Step 3: Marking a Linear Scale:</u>** *If zero represents an absolutely worthless system for the given scenario, and 100 represents the absolute best system imaginable for the given scenario,* mark the line where you think the "best" (B), "intermediate" (I), and "worst" (W) systems for each category, as ranked earlier, would fall on the line. **(Keep in mind the given scenario, i.e., a complete USW mission.)**

☐ • • • • • • • • • • • •

**•Weapons:** Worst:____________ Intermediate: ____________ Best:____________

Worthless system |---------+---------+---------+---------+---------+---------+---------+---------+---------+---------| Best system imaginable

0 10 20 30 40 50 60 70 80 90 100

**•Navigation:** Worst:____________ Intermediate: ____________ Best:____________

Worthless system |---------+---------+---------+---------+---------+---------+---------+---------+---------+---------| Best system imaginable

0 10 20 30 40 50 60 70 80 90 100

**•Communications:** Worst:____________ Intermediate: ____________ Best:____________

Worthless system |---------+---------+---------+---------+---------+---------+---------+---------+---------+---------| Best system imaginable

0 10 20 30 40 50 60 70 80 90 100

**•Sensors:** Worst:____________ Intermediate: ____________ Best:____________

Worthless system |---------+---------+---------+---------+---------+---------+---------+---------+---------+---------| Best system imaginable

0 10 20 30 40 50 60 70 80 90 100

**<u>Step 4(a): Let's Make a Deal!:</u>** You are outfitted with the system you have ranked as "intermediate". It is yours to employ in the given scenario. However, you have the option to trade in your current (intermediate) system for a <u>chance</u> at getting the "best" system. If you take the gamble and win, you get the "best" system. If you take the gamble and lose, you get the "worst" system. If you do not take the gamble, you keep the "intermediate" system. *What is the **minimum percentage chance of winning the "best" system** you are willing to accept in order to take the gamble?* **(Keep in mind the given scenario, i.e., a complete USW mission.)**

☐ • • • • • • • • • • • •

**•Weapons:** •You currently have the (Intermediate) ________________ weapon system.
•What is the ***<u>minimum</u> percentage chance of winning the*** *(Best)* __________ ***weapon system*** you are willing to accept in order to take the gamble (and risk getting the (Worst) ____________ weapon system)?

•_________ percent.

**•Navigation:** •You currently have the (Intermediate) ________________ navigation system.
•What is the ***<u>minimum</u> percentage chance of winning the*** *(Best)* __________ ***navigation system*** you are willing to accept in order to take the gamble (and risk getting the (Worst) ____________ navigation system)?

•_________ percent.

**•Communications:** •You currently have the (Intermediate) ____________ communications system.
•What is the ***<u>minimum</u> percentage chance of winning the*** *(Best)* __________ ***communications system*** you are willing to accept in order to take the gamble (and risk getting the (Worst) ____________ communications system)?

•_________ percent.

**•Sensors:** •You currently have the (Intermediate) ________________ sensor system.
•What is the ***<u>minimum</u> percentage chance of winning the*** *(Best)* __________ ***sensor system*** you are willing to accept in order to take the gamble (and risk getting the (Worst) ____________ sensor system)?

•_________ percent.

☐ • • • • • • • • • • • •

**Step 4(b): Let's Make a Deal! (Again!):** You are outfitted with the system you have ranked as "intermediate". It is yours to employ in the given scenario. However, you have the option to trade in your current (intermediate) system for a chance at getting the "best" system. If you take the gamble and win, you get the "best" system. If you take the gamble and lose, you get the "worst" system. If you do not take the gamble, you keep the "intermediate" system. *What is the **maximum** percentage chance of getting the "worst" system you are willing to accept in order to take the gamble?* **(Keep in mind the given scenario, i.e., a complete USW mission.)**

☐ • • • • • • • • • • • •

**•Weapons:** •You currently have the (Intermediate) ________________ weapon system.
•What is the ***maximum*** ***percentage chance of getting the*** (Worst) __________ ***weapon system*** you are willing to accept in order to risk the "intermediate" system gambling for the (Best) __________ weapon system?

• __________ percent.

**•Navigation:** •You currently have the (Intermediate) ________________ navigation system.
•What is the ***maximum*** ***percentage chance of getting the*** (Worst) __________ ***navigation system*** you are willing to accept in order to risk the "intermediate" system gambling for the (Best) __________ navigation system?

• __________ percent.

**•Communications:** •You currently have the (Intermediate) ____________ communications system.
•What is the ***maximum*** ***percentage chance of getting the*** (Worst) __________ ***communications system*** you are willing to accept in order to risk the "intermediate" system gambling for the (Best) __________ communication system?

• __________ percent.

**•Sensors:** •You currently have the (Intermediate) ________________ sensor system.
•What is the ***maximum*** ***percentage chance of getting the*** (Worst) __________ ***sensor system*** you are willing to accept in order to risk the "intermediate" system gambling for the (Best) __________ sensor system?

• __________ percent.

☐ • • • • • • • • • • • •

**Step 5: Subjective Rankings:** The four helicopter systems categories, *Weapons, Navigation, Communications*, and *Sensors*, are to be ranked (1) to (4) from *most important* (or *valuable*) to *least important* (or *valuable*) with respect **to the given mission scenario (i.e., a complete USW mission)**.

| | |
|---|---|
| Weapons | • ________ |
| Navigation | • ________ |
| Communications | • ________ |
| Sensors | • ________ |

☐ • • • • • • • • • • • •

**Step 6: Pairwise Comparisons:** You will now be asked to give your opinions on the *relative value* (or *importance*) **to the given mission scenario (i.e., a complete USW mission)** of the four systems categories, **compared two at a time**. Your answers will be placed in a partial matrix. Entries in the matrix will be numerical values of how much more important (or valuable) the *row* system category is relative to the *column* system category. For example, if the row system category is 10 times more valuable (important) for the USW mission than the column system category, you would enter a 10. If, on the other hand, the column category was three times more important than the row category, you would enter 1/3.

| | (2) [ ] | (3) [ ] | (4) [ ] |
|---|---|---|---|
| (1) [ ] | | | |
| (2) [ ] | | | |
| (3) [ ] | | | |

☐ • • • • • • • • • • • •

**Step 7: Unlimited Budget:** You are now outfitted with the systems you ranked as "worst" during the first part of the survey for all four of the system categories. If you were provided a budget that allowed you improve the systems from "worst" to "best" *in all four categories*, what proportion (percentage) of the budget would you allocate *to each category*? **(Keep in mind the given scenario, i.e., a complete USW mission.)**

| | |
|---|---|
| Weapons | |
| Navigation | |
| Communications | |
| Sensors | |
| TOTAL | 100 |

☐ • • • • • • • • • • • •

**<u>Step 8: Let's *Really* Make a Deal!:</u>** You are outfitted with the "best" system in one system category, and the "worst" systems in the remaining three system categories. This system suite is yours to employ **in the given scenario (complete USW mission)**. However, you have the option to trade in your current (one "best" and three "worsts") suite for a <u>chance</u> at getting the "best" systems in *all four* system categories. If you take the gamble and win, you get the "best" systems in all four system categories. The downside is, if you take the gamble and lose, you get the "worst" systems in all four categories. If you do not take the gamble, you keep the system suite you have been given (one "best" and three "worsts"). ***What is the <u>min</u>imum percentage chance of winning the "best" systems in all four system categories** you are willing to accept in order to take the gamble?*

| | Weapon | Nav | Comms | Sensors |
|---|---|---|---|---|
| Given System Suite.. | (Best) | (Worst) | (Worst) | (Worst) |
| Win Gamble............ | (Best) | (Best) | (Best) | (Best) |
| Lose Gamble........... | (Worst) | (Worst) | (Worst) | (Worst) |

•***<u>Min</u>*imum percentage chance of winning in order to take gamble:**

| | Weapon | Nav | Comms | Sensors |
|---|---|---|---|---|
| Given System Suite.. | (Worst) | (Best) | (Worst) | (Worst) |
| Win Gamble............ | (Best) | (Best) | (Best) | (Best) |
| Lose Gamble........... | (Worst) | (Worst) | (Worst) | (Worst) |

•***<u>Min</u>*imum percentage chance of winning in order to take gamble:**

| | Weapon | Nav | Comms | Sensors |
|---|---|---|---|---|
| Given System Suite.. | (Worst) | (Worst) | (Best) | (Worst) |
| Win Gamble............ | (Best) | (Best) | (Best) | (Best) |
| Lose Gamble........... | (Worst) | (Worst) | (Worst) | (Worst) |

•***<u>Min</u>*imum percentage chance of winning in order to take gamble:**

| | Weapon | Nav | Comms | Sensors |
|---|---|---|---|---|
| Given System Suite.. | (Worst) | (Worst) | (Worst) | (Best) |
| Win Gamble............ | (Best) | (Best) | (Best) | (Best) |
| Lose Gamble........... | (Worst) | (Worst) | (Worst) | (Worst) |

•***<u>Min</u>*imum percentage chance of winning in order to take gamble:**

**Step 9: Decision Maker Background Information:**

•Community / years-months experience (include FRS): •Mk-I / ______ •Mk-III / ______

•Other military aviation experience: ______________________________

•Year Group: ____________

•LAMPS flight hours: ___________ •Total flight hours (military): _____________

•Months LAMPS at sea time: __________

•Have you ever worked and/or flown with:
- •Depth Charges: Y / N
- •GPS: Y / N
- •Sat Com: Y / N
- •FLIR: Y / N

•LAMPS FRS:
- •Mayport
- •North Island
- •Other : ____________

•LAMPS Homeport(s): (Excluding FRS)
- •Mayport
- •North Island
- •Barbers Point
- •Atsugi
- •Other(s): _________________

•SWATS Grad?: Y / N

•Type platform(s) on which conducted LAMPS cruise:
- •FFG-7
- •DD-963
- •CG-47
- •DD-1052
- •Other(s): _________________
- • _______________________

•"Actual" USW time (hours) on "non friendly" submarine(s): ______________________

•Any special tactics schools you have attended (e.g., SWATS): ____________________

•Experience with experimental equipment / R&D tests for LAMPS applications (e.g., LIDAR, Magic Lantern, FLIR, RDP (Radar Data Processor), Penguin, etc.) (Keep it UNCLAS please):

________________________________________________________________

________________________________________________________________

•Any comments on survey as a whole (No holds barred!) ______________________

________________________________________________________________

________________________________________________________________

•What other background questions should I have asked?: ______________________

________________________________________________________________

# APPENDIX C. SUMMARY TABLE OF RAW DATA

| | Survey Step 1: SUBJECTIVE RANKINGS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weapons Ranking | | | Navigation Ranking | | | Communications Rankin | | | Sensor Ranking | | | |
| | Mk-46 | 500# | Mk-50 | GPS | TACAN | Doppler | D/L | SatCom | Radio | MAD | Radar | FLIR | |
| 1 | 2 | 3 | 1 | 3 | 1 | 2 | 2 | 3 | 1 | 3 | 1 | 2 | 1 |
| 2 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 3 | 2 | 2 | 1 | 3 | 2 |
| 3 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 3 | 1 | 2 | 3 |
| 4 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 2 | 1 | 4 |
| 5 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 2 | 3 | 3 | 1 | 2 | 5 |
| 6 | 2 | 3 | 1 | 2 | 3 | 1 | 1 | 3 | 2 | 2 | 1 | 3 | 6 |
| 7 | 2 | 3 | 1 | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 3 | 2 | 7 |
| 8 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 2 | 3 | 3 | 2 | 1 | 8 |
| 9 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 1 | 3 | 3 | 2 | 1 | 9 |
| 10 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 3 | 1 | 2 | 10 |
| 11 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 3 | 2 | 1 | 2 | 3 | 11 |
| 12 | 3 | 2 | 1 | 1 | 2 | 3 | 2 | 1 | 3 | 2 | 1 | 3 | 12 |
| 13 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 2 | 3 | 3 | 1 | 2 | 13 |
| 14 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 14 |
| 15 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 15 |
| 16 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 2 | 3 | 2 | 1 | 3 | 16 |
| 17 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 17 |
| 18 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 3 | 2 | 1 | 2 | 3 | 18 |
| 19 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 3 | 2 | 2 | 3 | 1 | 19 |
| 20 | 3 | 2 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 20 |
| 21 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 3 | 2 | 21 |
| 22 | 2 | 3 | 1 | 1 | 3 | 2 | 1 | 3 | 2 | 2 | 1 | 3 | 22 |
| 23 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 23 |
| 24 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 1 | 3 | 2 | 1 | 3 | 24 |
| 25 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 1 | 2 | 3 | 25 |
| 26 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 3 | 1 | 2 | 1 | 3 | 26 |
| 27 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 27 |
| 28 | | | | | | | | | | | | | 28 |
| 29 | | | | | | | | | | | | | 29 |
| 30 | | | | | | | | | | | | | 30 |

Survey Step 2(a): QUANTITATIVE ASSESSMENT (Pairwise Comparisons)

| | Weapons | | | Navigation | | | Communications | | | Sensors | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B vs I | B vs W | I vs W | B vs I | B vs W | I vs W | B vs I | B vs W | I vs W | B vs I | B vs W | I vs W | |
| 1 | 2 | 4 | 2 | 3 | 2 | 1 | 2 | 1.00001 | 1 | 2 | 1 | 3 | 1 |
| 2 | 3 | 10 | 5 | 20 | 10 | 5 | 2 | 1000 | 10000 | 5 | 1.5 | 2 | 2 |
| 3 | 2 | 2 | 4 | 10 | 10 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 3 |
| 4 | 1.5 | 10 | 5 | 2 | 10 | 5 | 2 | 3 | 2 | 1.5 | 10 | 5 | 4 |
| 5 | 2 | 10 | 5 | 5 | 10 | 5 | 10 | 20 | 10 | 10 | 20 | 5 | 5 |
| 6 | 5 | 20 | 10 | 2 | 5 | 5 | 5 | 10 | 5 | 2 | 5 | 5 | 6 |
| 7 | 5 | 10 | 5 | 50 | 10 | 5 | 5 | 10 | 5 | 5 | 3 | 3 | 7 |
| 8 | 2 | 10 | 5 | 4 | 10 | 2 | 1.5 | 5 | 3 | 2 | 10 | 5 | 8 |
| 9 | 2 | 10 | 5 | 10 | 20 | 2 | 4 | 20 | 5 | 1.5 | 20 | 18.5 | 9 |
| 10 | 4 | 10 | 6 | 4 | 6 | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 10 |
| 11 | 5 | 50 | 10 | 100 | 200 | 2 | 100 | 100 | 1.1 | 1.1 | 1.2 | 1.1 | 11 |
| 12 | 5 | 5 | 2 | 10 | 15 | 5 | 10 | 20 | 10 | 10 | 20 | 5 | 12 |
| 13 | 3 | 10 | 5 | 10 | 50 | 5 | 2 | 10 | 5 | 3 | 2 | 1.5 | 13 |
| 14 | 2 | 3 | 2 | 4 | 6 | 2 | 2 | 4 | 6 | 2 | 3 | 2 | 14 |
| 15 | 4 | 7 | 3 | 5 | 10 | 2 | 2 | 4 | 3 | 3 | 4 | 2 | 15 |
| 16 | 2 | 3 | 1.5 | 2 | 3 | 1.5 | 1.5 | 4 | 3 | 1.5 | 1.7 | 1.1 | 16 |
| 17 | 2 | 3 | 2 | 10 | 100 | 10 | 5 | 10 | 2 | 2 | 5 | 2 | 17 |
| 18 | 3 | 10 | 5 | 2 | 20 | 10 | 4 | 4 | 2 | 2 | 10 | 5 | 18 |
| 19 | 2 | 1000 | 900 | 10 | 1000 | 100 | 3 | 100 | 90 | 2 | 5 | 2 | 19 |
| 20 | 2 | 3 | 1.5 | 10 | 20 | 5 | 3 | 10 | 3 | 4 | 20 | 10 | 20 |
| 21 | 2 | 10 | 5 | 10 | 20 | 2 | 2 | 4 | 2 | 4 | 8 | 2 | 21 |
| 22 | 5 | 10 | 8 | 10 | 50 | 5 | 25 | 50 | 5 | 5 | 10 | 5 | 22 |
| 23 | 10 | 100 | 10 | 10 | 20 | 2 | 2 | 10 | 5 | 2 | 4 | 2 | 23 |
| 24 | 1.5 | 4 | 2 | 5 | 25 | 5 | 3 | 15 | 5 | 1.5 | 3 | 2 | 24 |
| 25 | 1.5 | 3 | 1.5 | 2 | 3 | 2 | 1.5 | 2 | 1.5 | 2 | 3 | 1.5 | 25 |
| 26 | 3 | 5 | 2 | 3 | 5 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 26 |
| 27 | 2 | 5 | 3 | 5 | 10 | 3 | 2 | 5 | 2 | 2 | 10 | 5 | 27 |
| 28 | | | | | | | | | | | | | 28 |
| 29 | | | | | | | | | | | | | 29 |
| 30 | | | | | | | | | | | | | 30 |

| | Survey Step 2(b): QUANTITATIVE ASSESSMENT (cont.) (Pairwise Comparisons) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weapons | | | Navigation | | | Communications | | | Sensors | | | |
| | W vs B | W vs I | I vs B | W vs B | W vs I | I vs B | W vs B | W vs I | I vs B | W vs B | W vs I | I vs B | |
| 1 | 2 | 1 | 2 | 1 | 1 | 3 | 1 | 2 | 2 | 3 | 3 | 1 | 1 |
| 2 | 20 | 10 | 3 | 20 | 10 | 5 | 10000 | 1000 | 5 | 15 | 5 | 3 | 2 |
| 3 | 4 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 4 | 2 | 2 | 3 |
| 4 | 10 | 5 | 1.5 | 10 | 5 | 2 | 3 | 2 | 1.5 | 10 | 5 | 1.5 | 4 |
| 5 | 10 | 5 | 2 | 10 | 5 | 8 | 20 | 10 | 10 | 10 | 5 | 5 | 5 |
| 6 | 20 | 10 | 5 | 5 | 10 | 2 | 5 | 2 | 2 | 5 | 2 | 2 | 6 |
| 7 | 10 | 5 | 5 | 20 | 10 | 20 | 10 | 5 | 2 | 5 | 3 | 2 | 7 |
| 8 | 10 | 5 | 2 | 10 | 2 | 3 | 5 | 3 | 1.5 | 8 | 4 | 2 | 8 |
| 9 | 10 | 5 | 2 | 20 | 4 | 5 | 20 | 10 | 2 | 20 | 18 | 1.5 | 9 |
| 10 | 8 | 4 | 4 | 4 | 2 | 2 | 4 | 2 | 2 | 4 | 2 | 2 | 10 |
| 11 | 500 | 100 | 5 | 200 | 2 | 100 | 110 | 1.1 | 100 | 1.2 | 1.1 | 1.1 | 11 |
| 12 | 5 | 5 | 10 | 20 | 10 | 10 | 20 | 10 | 10 | 10 | 5 | 5 | 12 |
| 13 | 10 | 5 | 2 | 10 | 5 | 5 | 10 | 5 | 2 | 10 | 5 | 2 | 13 |
| 14 | 4 | 3 | 2 | 4 | 3 | 3 | 6 | 4 | 4 | 3 | 2 | 2 | 14 |
| 15 | 8 | 4 | 3 | 10 | 3 | 7 | 5 | 4 | 2 | 7 | 6 | 2 | 15 |
| 16 | 3 | 2 | 1.5 | 3 | 2 | 1.5 | 4 | 2 | 2 | 2.2 | 1.5 | 1.5 | 16 |
| 17 | 3 | 2 | 2 | 100 | 10 | 10 | 10 | 5 | 5 | 10 | 5 | 2 | 17 |
| 18 | 20 | 10 | 3 | 10 | 8 | 4 | 4 | 2 | 2 | 10 | 5 | 2 | 18 |
| 19 | 1000 | 900 | 2 | 100 | 10 | 100 | 10 | 5 | 2 | 5 | 2 | 2 | 19 |
| 20 | 3 | 2 | 2 | 20 | 10 | 10 | 20 | 10 | 3 | 50 | 30 | 5 | 20 |
| 21 | 4 | 2 | 2 | 20 | 2 | 10 | 8 | 2 | 4 | 8 | 2 | 4 | 21 |
| 22 | 10 | 5 | 5 | 10 | 5 | 8 | 50 | 5 | 25 | 10 | 5 | 5 | 22 |
| 23 | 100 | 10 | 10 | 20 | 2 | 10 | 10 | 5 | 2 | 10 | 2 | 5 | 23 |
| 24 | 10 | 5 | 2 | 20 | 10 | 5 | 20 | 5 | 4 | 3 | 2 | 2 | 24 |
| 25 | 3 | 1.5 | 1.5 | 3 | 1.5 | 1.5 | 2 | 1.5 | 1.5 | 2 | 1.5 | 1.5 | 25 |
| 26 | 5 | 3 | 2 | 5 | 3 | 2 | 4 | 2 | 2 | 4 | 2 | 2 | 26 |
| 27 | 10 | 5 | 2 | 10 | 2 | 5 | 10 | 5 | 2 | 10 | 5 | 2 | 27 |
| 28 | | | | | | | | | | | | | 28 |
| 29 | | | | | | | | | | | | | 29 |
| 30 | | | | | | | | | | | | | 30 |

| | Survey Step 3: MARKING A LINEAR SCALE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weapons | | | Navigation | | | Communications | | | Sensors | | | |
| | W | I | B | W | I | B | W | I | B | W | I | B | |
| 1 | 34.5 | 50 | 70 | 40 | 45.5 | 69.5 | 35 | 45 | 64.5 | 40 | 55 | 70 | 1 |
| 2 | 5.5 | 50 | 70 | 20 | 40 | 84.5 | 1 | 70 | 90 | 46 | 51 | 60.5 | 2 |
| 3 | 30 | 50 | 70 | 45 | 50 | 90 | 45 | 50 | 75 | 40 | 50 | 60 | 3 |
| 4 | 14 | 34.5 | 54 | 25 | 55 | 74.5 | 44.5 | 64 | 74 | 15 | 55 | 74.5 | 4 |
| 5 | 29.5 | 50.5 | 60.5 | 49.5 | 60 | 80 | 40 | 49.5 | 85.5 | 34.54 | 40 | 50 | 5 |
| 6 | 9.5 | 50 | 75 | 50 | 70 | 80 | 50 | 80.5 | 100 | 69.5 | 75 | 80 | 6 |
| 7 | 30 | 60 | 85 | 70.0 | 75.0 | 94.5 | 70 | 84 | 94 | 50 | 70 | 80 | 7 |
| 8 | 12 | 50 | 91 | 21.5 | 65.5 | 93.5 | 44.5 | 59.5 | 77.5 | 23 | 62.5 | 80 | 8 |
| 9 | 4 | 30 | 50 | 10 | 64 | 94 | 23 | 40 | 96 | 9.5 | 23.5 | 41 | 9 |
| 10 | 20 | 40 | 80 | 40 | 60 | 90 | 20 | 60 | 80 | 30 | 40 | 60 | 10 |
| 11 | 10 | 45.0 | 90 | 3.5 | 11.5 | 90 | 15 | 19.5 | 90 | 24 | 26 | 29.5 | 11 |
| 12 | 50 | 60 | 79.5 | 60 | 70.5 | 90 | 60 | 71 | 91 | 29.5 | 50 | 79 | 12 |
| 13 | 14.5 | 40 | 66.5 | 5 | 30 | 80.5 | 24 | 50 | 75 | 20 | 38 | 50.5 | 13 |
| 14 | 5 | 20 | 40 | 30 | 50 | 80 | 30 | 60 | 90 | 10 | 20 | 30 | 14 |
| 15 | 30 | 50 | 60.5 | 30 | 50 | 90 | 50 | 70.5 | 80 | 40 | 65.5 | 70 | 15 |
| 16 | 14 | 30 | 53.5 | 25.5 | 57 | 80 | 27 | 50 | 60 | 42 | 46.5 | 50.5 | 16 |
| 17 | 38.5 | 50 | 75.5 | 50 | 75 | 92.5 | 55 | 65.5 | 75 | 52.5 | 55.5 | 75 | 17 |
| 18 | 10 | 70 | 90 | 30 | 70 | 90 | 70.5 | 80 | 90 | 10 | 50 | 60 | 18 |
| 19 | 7 | 20 | 25.5 | 19.5 | 40 | 98.5 | 17 | 20 | 70 | 10.5 | 33.5 | 40 | 19 |
| 20 | 40.5 | 53 | 62.5 | 33.5 | 41 | 77 | 49.5 | 64 | 69.5 | 17 | 63.5 | 66 | 20 |
| 21 | 20 | 50 | 70 | 50 | 60 | 96.5 | 50 | 73.5 | 80 | 30 | 43.5 | 50 | 21 |
| 22 | 10 | 40 | 54 | 30 | 43.5 | 60 | 27.5 | 35 | 54.5 | 19.5 | 34.5 | 44.5 | 22 |
| 23 | 10 | 50 | 80 | 30 | 50 | 80 | 40 | 70 | 80 | 20 | 30 | 50 | 23 |
| 24 | 30 | 50.5 | 60 | 37 | 64 | 94 | 45.5 | 73 | 94.5 | 44 | 60 | 69 | 24 |
| 25 | 50 | 64.5 | 80 | 70 | 80 | 94.5 | 64.5 | 69.5 | 80 | 30 | 40 | 50 | 25 |
| 26 | 20 | 60 | 80 | 30 | 50 | 80 | 30 | 60 | 80 | 40 | 60 | 80 | 26 |
| 27 | 10 | 25 | 50 | 20 | 35 | 75 | 20 | 50 | 60 | 5 | 20 | 25 | 27 |
| 28 | | | | | | | | | | | | | 28 |
| 29 | | | | | | | | | | | | | 29 |
| 30 | | | | | | | | | | | | | 30 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | INDIFFERENCE PROBABILITY | | | | | | |
| | Survey Step 4(a): LET'S MAKE A DEAL | | | | | Survey Step 4(b): LET'S MAKE A DEAL (Again) | | | | |
| | Weaps | Nav | Comms | Sensor | | Weaps | Nav | Comms | Sensor | |
| | % | % | % | % | | % | % | % | % | |
| 1 | 80 | 25 | 70 | 65 | | 10 | 30 | 20 | 10 | 1 |
| 2 | 96 | 70 | 50 | 85 | | 4 | 20 | 30 | 15 | 2 |
| 3 | 80 | 10 | 60 | 50 | | 20 | 80 | 10 | 50 | 3 |
| 4 | 20 | 30 | 60 | 20 | | 20 | 20 | 50 | 20 | 4 |
| 5 | 80 | 75 | 50 | 99 | | 20 | 25 | 50 | 1 | 5 |
| 6 | 100 | 60 | 40 | 75 | | 10 | 40 | 60 | 25 | 6 |
| 7 | 40 | 30 | 80 | 50 | | 60 | 80 | 30 | 20 | 7 |
| 8 | 85 | 30 | 80 | 95 | | 10 | 80 | 25 | 10 | 8 |
| 9 | 60 | 60 | 40 | 40 | | 40 | 40 | 60 | 60 | 9 |
| 10 | 80 | 60 | 60 | 60 | | 20 | 40 | 40 | 40 | 10 |
| 11 | 20 | 0 | 0 | 0 | | 80 | 100 | 100 | 100 | 11 |
| 12 | 20 | 95 | 95 | 90 | | 95 | 10 | 10 | 10 | 12 |
| 13 | 80 | 80 | 20 | 51 | | 20 | 20 | 80 | 49 | 13 |
| 14 | 80 | 50 | 60 | 50 | | 20 | 40 | 30 | 40 | 14 |
| 15 | 95 | 75 | 50 | 50 | | 10 | 20 | 50 | 55 | 15 |
| 16 | 60 | 70 | 50 | 60 | | 30 | 30 | 40 | 40 | 16 |
| 17 | 80 | 95 | 50 | 50 | | 20 | 5 | 80 | 50 | 17 |
| 18 | 70 | 90 | 30 | 50 | | 30 | 10 | 70 | 50 | 18 |
| 19 | 95 | 1 | 5 | 25 | | 5 | 40 | 90 | 90 | 19 |
| 20 | 30 | 70 | 65 | 10 | | 40 | 30 | 40 | 10 | 20 |
| 21 | 85 | 50 | 75 | 60 | | 10 | 70 | 15 | 30 | 21 |
| 22 | 90 | 55 | 40 | 45 | | 10 | 45 | 65 | 55 | 22 |
| 23 | 90 | 100 | 30 | 75 | | 0 | 50 | 50 | 50 | 23 |
| 24 | 70 | 40 | 40 | 75 | | 40 | 25 | 85 | 30 | 24 |
| 25 | 75 | 5 | 70 | 50 | | 25 | 95 | 40 | 50 | 25 |
| 26 | 60 | 60 | 70 | 50 | | 30 | 60 | 30 | 30 | 26 |
| 27 | 50 | 70 | 75 | 85 | | 15 | 30 | 15 | 5 | 27 |
| 28 | | | | | | | | | | 28 |
| 29 | | | | | | | | | | 29 |
| 30 | | | | | | | | | | 30 |

| | Survey Step 5: SUBJECTIVE RANKINGS | | | | |
|---|---|---|---|---|---|
| | Weaps Rank | Nav Rank | Comms Rank | Sensor Rank | |
| 1 | 3 | 1 | 4 | 2 | 1 |
| 2 | 3 | 2 | 4 | 1 | 2 |
| 3 | 2 | 3 | 4 | 1 | 3 |
| 4 | 3 | 2 | 1 | 4 | 4 |
| 5 | 3 | 2 | 4 | 1 | 5 |
| 6 | 4 | 2 | 3 | 1 | 6 |
| 7 | 3 | 2 | 4 | 1 | 7 |
| 8 | 2 | 3 | 4 | 1 | 8 |
| 9 | 1 | 4 | 3 | 2 | 9 |
| 10 | 2 | 3 | 4 | 1 | 10 |
| 11 | 2 | 3 | 4 | 1 | 11 |
| 12 | 1 | 3 | 4 | 2 | 12 |
| 13 | 2 | 3 | 4 | 1 | 13 |
| 14 | 4 | 3 | 2 | 1 | 14 |
| 15 | 4 | 2 | 3 | 1 | 15 |
| 16 | 3 | 2 | 4 | 1 | 16 |
| 17 | 2 | 3 | 4 | 1 | 17 |
| 18 | 3 | 2 | 4 | 1 | 18 |
| 19 | 1 | 3 | 2 | 4 | 19 |
| 20 | 4 | 2 | 3 | 1 | 20 |
| 21 | 3 | 2 | 4 | 1 | 21 |
| 22 | 3 | 1 | 4 | 2 | 22 |
| 23 | 2 | 3 | 4 | 1 | 23 |
| 24 | 2 | 1 | 3 | 4 | 24 |
| 25 | 3 | 2 | 4 | 1 | 25 |
| 26 | 1 | 4 | 3 | 2 | 26 |
| 27 | 4 | 3 | 1 | 2 | 27 |
| 28 | | | | | 28 |
| 29 | | | | | 29 |
| 30 | | | | | 30 |

| | Survey Step 6: PAIRWISE COMPARISONS (Attribute) | | | | | | |
|---|---|---|---|---|---|---|---|
| | | (Row #), (Column #) | | | | | |
| | (1), (2) | (1), (3) | (1), (4) | (2), (3) | (2), (4) | (3), (4) | |
| 1 | 2 | 3 | 5 | 2 | 4 | 2 | 1 |
| 2 | 5 | 10 | 20 | 2 | 4 | 2 | 2 |
| 3 | 2 | 8 | 16 | 4 | 8 | 2 | 3 |
| 4 | 1.5 | 1.6 | 2 | 2 | 3 | 2 | 4 |
| 5 | 2 | 3 | 5 | 2 | 3 | 3 | 5 |
| 6 | 2 | 3 | 5 | 2 | 4 | 3 | 6 |
| 7 | 2 | 3 | 4 | 2 | 3 | 4 | 7 |
| 8 | 2 | 4 | 5 | 2 | 2 | 1.5 | 8 |
| 9 | 2 | 4 | 6 | 2 | 4 | 2 | 9 |
| 10 | 2 | 2 | 4 | 0.5 | 2 | 2 | 10 |
| 11 | 100 | 1000 | 10000 | 10 | 100 | 10 | 11 |
| 12 | 5 | 10 | 10 | 5 | 2 | 3 | 12 |
| 13 | 1.25 | 1.5 | 3 | 1.25 | 2.75 | 2.5 | 13 |
| 14 | 2 | 4 | 5 | 2 | 4 | 2 | 14 |
| 15 | 2 | 3 | 8 | 2 | 6 | 5 | 15 |
| 16 | 1.1 | 1.5 | 2 | 1.4 | 2 | 1.4 | 16 |
| 17 | 1 | 1 | 1 | 1 | 1 | 1 | 17 |
| 18 | 1 | 2 | 10 | 1 | 5 | 10 | 18 |
| 19 | 2 | 5 | 6 | 2 | 4 | 4 | 19 |
| 20 | 2 | 3 | 5 | 2 | 4 | 3 | 20 |
| 21 | 3 | 9 | 18 | 3 | 6 | 2 | 21 |
| 22 | 3 | 5 | 8 | 5 | 8 | 2 | 22 |
| 23 | 2 | 4 | 10 | 2 | 5 | 2 | 23 |
| 24 | 2 | 10 | 11 | 3 | 4 | 1.5 | 24 |
| 25 | 2 | 2.5 | 4 | 1.5 | 2 | 1.5 | 25 |
| 26 | 2 | 4 | 6 | 3 | 5 | 4 | 26 |
| 27 | 2 | 3 | 4 | 2 | 4 | 2 | 27 |
| 28 | | | | | | | 28 |
| 29 | | | | | | | 29 |
| 30 | | | | | | | 30 |

| | Survey Step 7: UNLIMITED BUDGET | | | | | Survey Step 8: LET'S *REALLY* MAKE A DEA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weaps | Nav | Comms | Sensor | | Weaps | Nav | Comms | Sensor | |
| | % | % | % | % | | % | % | % | % | |
| 1 | 20 | 40 | 10 | 30 | | 60 | 40 | 25 | 50 | 1 |
| 2 | 50 | 10 | 20 | 20 | | 15 | 96 | 96 | 96 | 2 |
| 3 | 70 | 10 | 20 | 10 | | 25 | 25 | 20 | 10 | 3 |
| 4 | 20 | 30 | 40 | 10 | | 20 | 40 | 60 | 70 | 4 |
| 5 | 10 | 10 | 30 | 50 | | 40 | 80 | 80 | 70 | 5 |
| 6 | 40 | 15 | 15 | 30 | | 33 | 40 | 50 | 67 | 6 |
| 7 | 30 | 20 | 10 | 40 | | 60 | 20 | 20 | 20 | 7 |
| 8 | 30 | 20 | 10 | 40 | | 75 | 20 | 5 | 30 | 8 |
| 9 | 40 | 10 | 20 | 30 | | 70 | 40 | 40 | 40 | 9 |
| 10 | 40 | 30 | 10 | 20 | | 80 | 50 | 50 | 50 | 10 |
| 11 | 80 | 10 | 0 | 10 | | 95 | 0 | 0 | 0 | 11 |
| 12 | 30 | 20 | 30 | 20 | | 20 | 10 | 10 | 10 | 12 |
| 13 | 32.5 | 32.5 | 15 | 20 | | 30 | 45 | 40 | 30 | 13 |
| 14 | 20 | 20 | 30 | 30 | | 30 | 20 | 20 | 20 | 14 |
| 15 | 35 | 50 | 10 | 5 | | 75 | 95 | 65 | 45 | 15 |
| 16 | 30 | 20 | 20 | 30 | | 10 | 40 | 30 | 10 | 16 |
| 17 | 40 | 10 | 20 | 30 | | 80 | 80 | 85 | 50 | 17 |
| 18 | 30 | 40 | 20 | 10 | | 20 | 50 | 10 | 10 | 18 |
| 19 | 95 | 0 | 4 | 1 | | 99 | 1 | 1 | 1 | 19 |
| 20 | 5 | 25 | 20 | 50 | | 15 | 45 | 35 | 55 | 20 |
| 21 | 25 | 30 | 20 | 25 | | 50 | 75 | 25 | 40 | 21 |
| 22 | 25 | 40 | 15 | 20 | | 65 | 85 | 40 | 45 | 22 |
| 23 | 70 | 10 | 10 | 10 | | 95 | 30 | 30 | 30 | 23 |
| 24 | 30 | 40 | 10 | 20 | | 20 | 88 | 60 | 20 | 24 |
| 25 | 30 | 40 | 5 | 25 | | 40 | 60 | 10 | 35 | 25 |
| 26 | 40 | 30 | 10 | 20 | | 20 | 20 | 30 | 30 | 26 |
| 27 | 10 | 20 | 30 | 40 | | 15 | 25 | 35 | 35 | 27 |
| 28 | | | | | | | | | | 28 |
| 29 | | | | | | | | | | 29 |
| 30 | | | | | | | | | | 30 |

## APPENDIX D. SUPPLEMENTARY CONSISTENCY PLOTS OF DATA SUBSETS

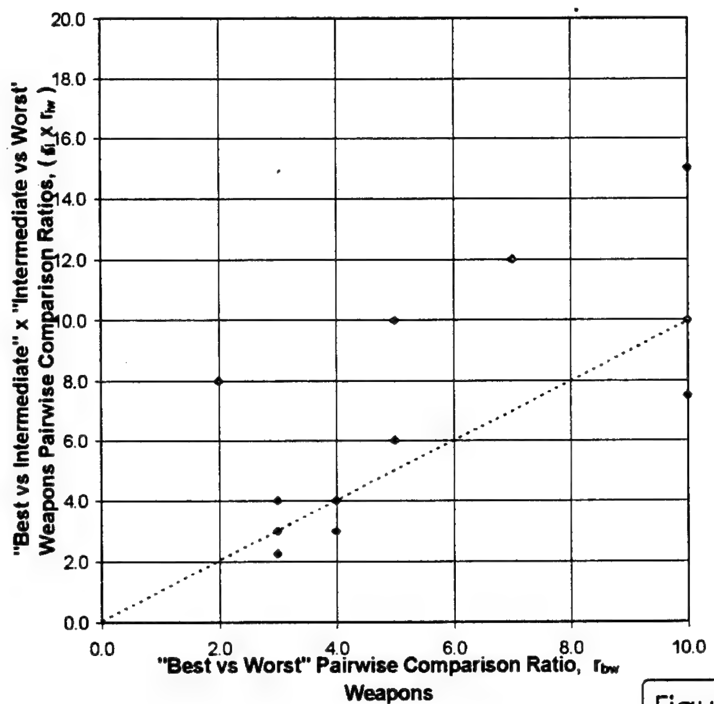



Figure A.D-1

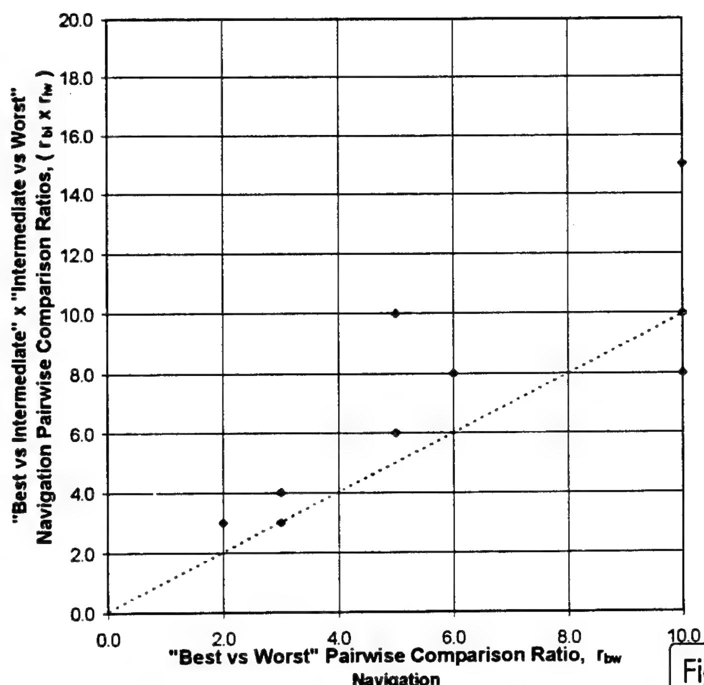



Figure A.D-2

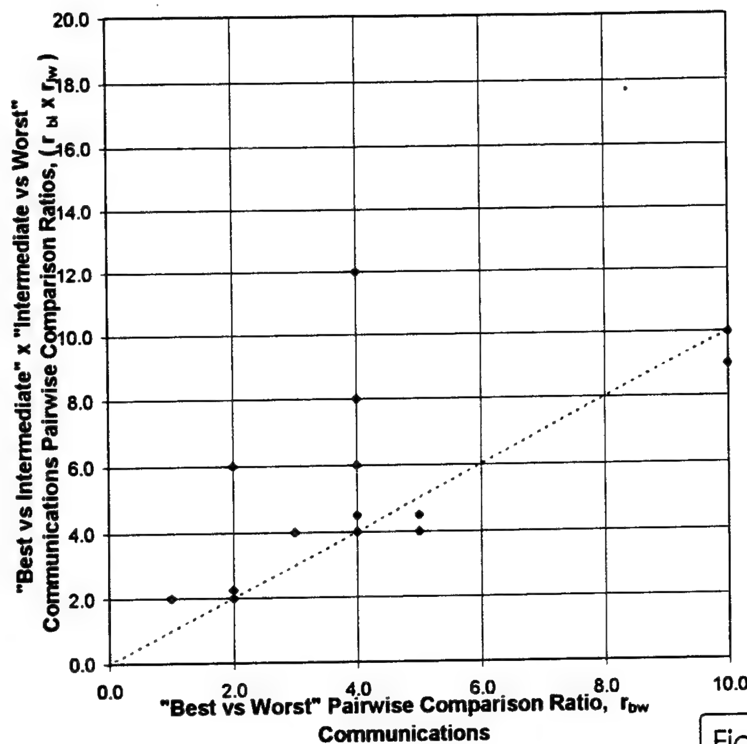



Figure A.D-3

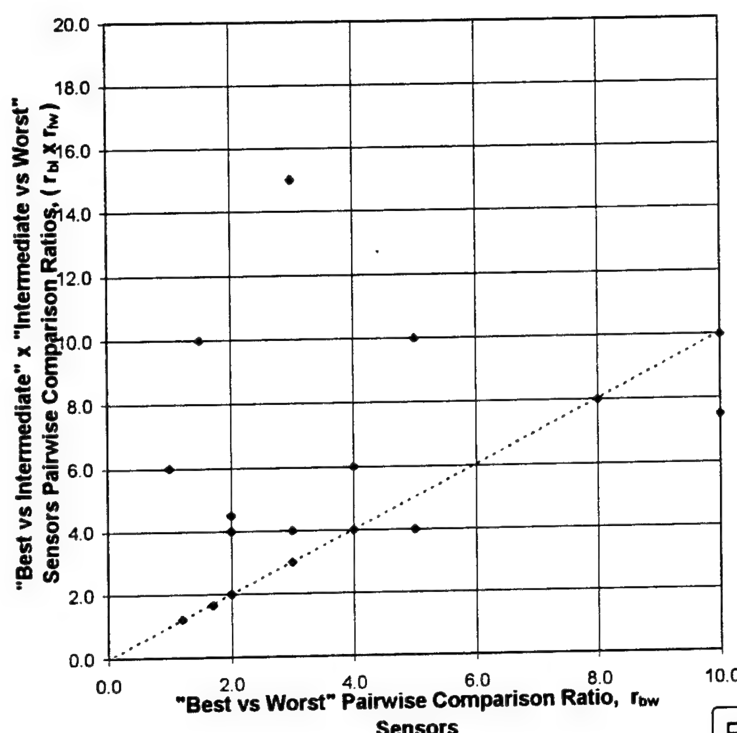



Figure A.D-4

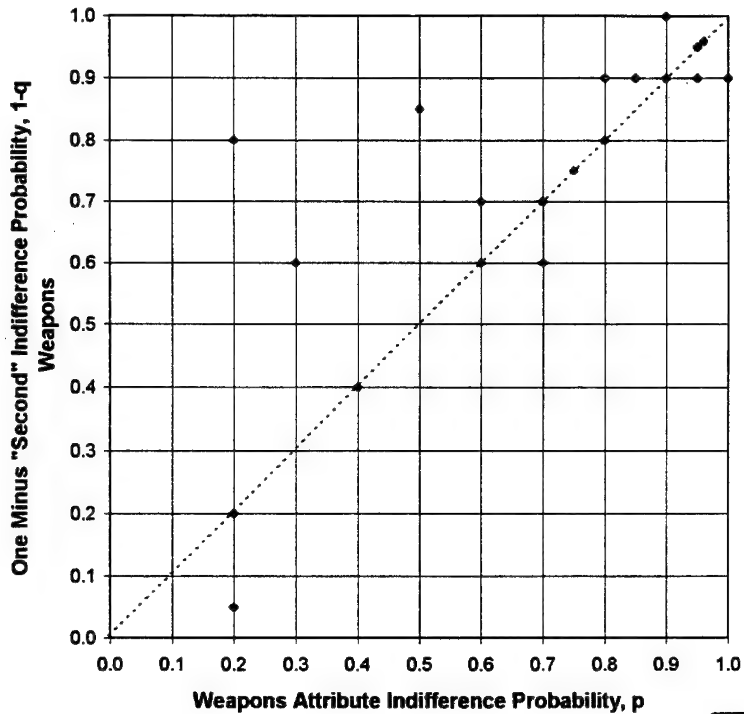



Figure A.D-5

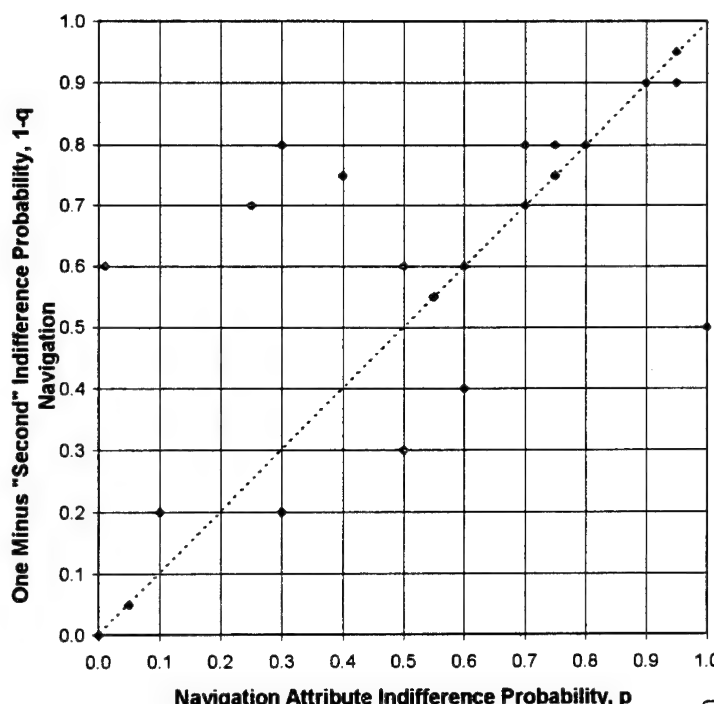



Figure A.D-6

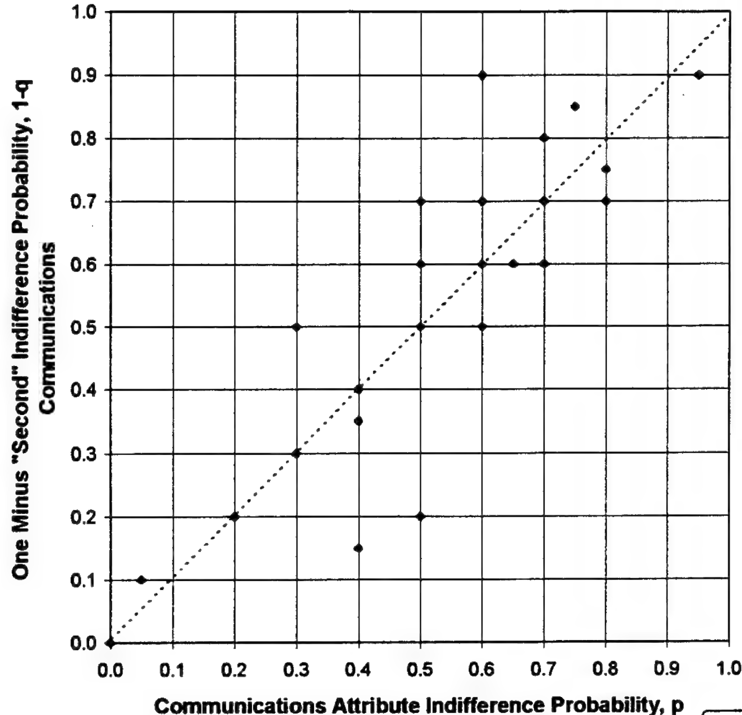



Figure A.D-7

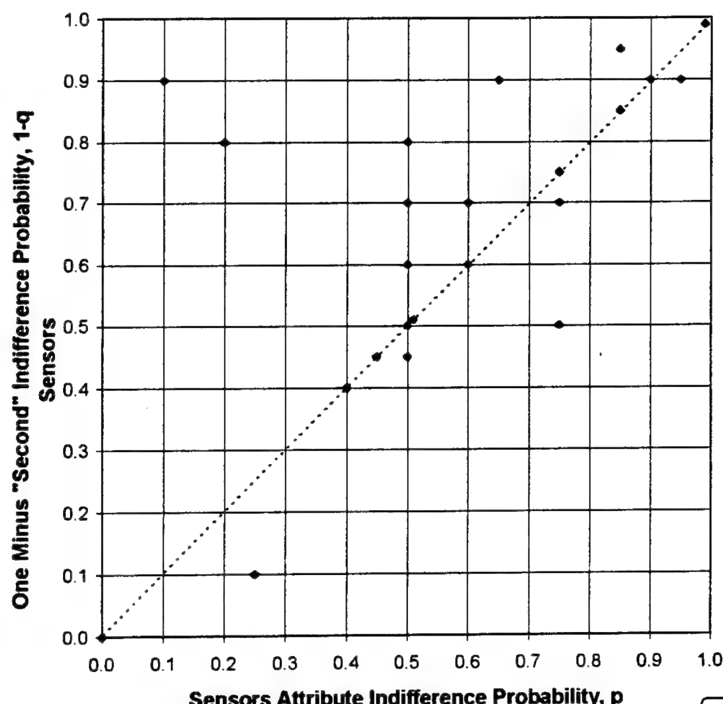



Figure A.D-8

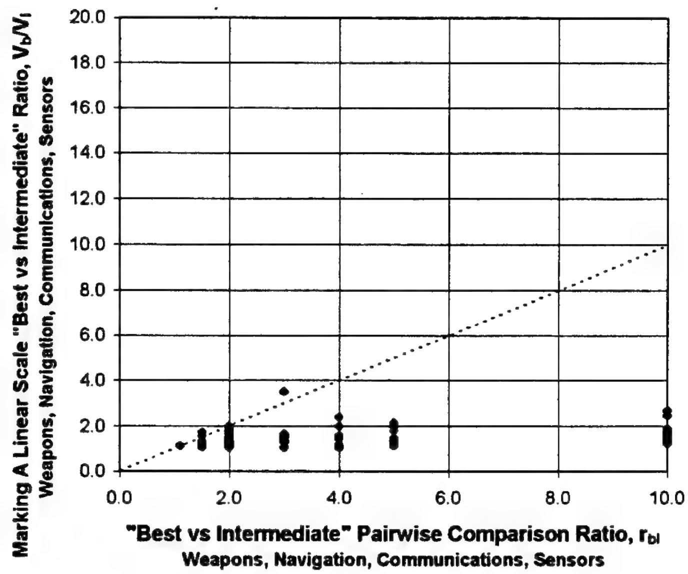



Figure A.D-9

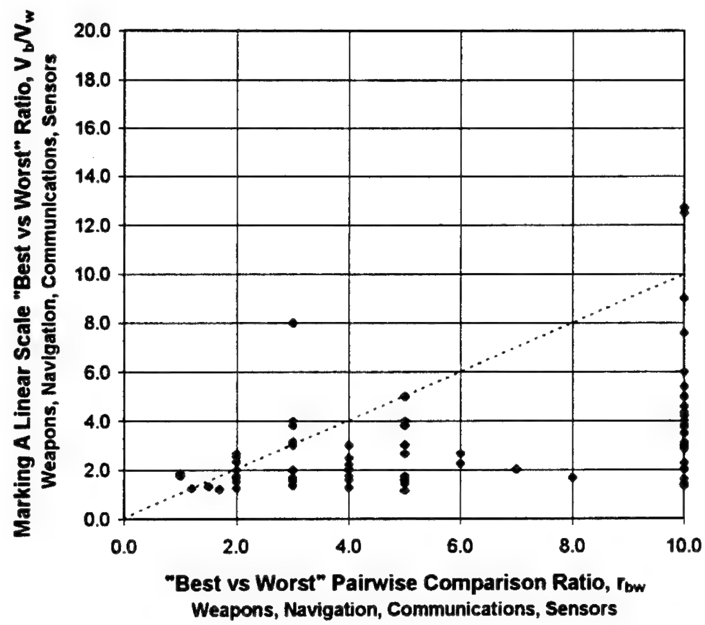
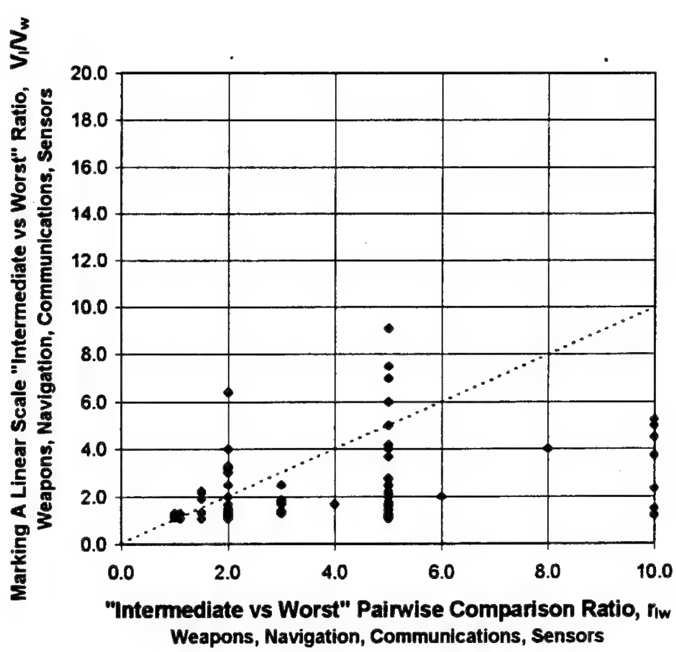



Figure A.D-10



Marking A Linear Scale "Intermediate vs Worst" Ratio, $V_i/V_w$
Weapons, Navigation, Communications, Sensors
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
"Intermediate vs Worst" Pairwise Comparison Ratio, $r_{iw}$
Weapons, Navigation, Communications, Sensors


Figure A.D-11

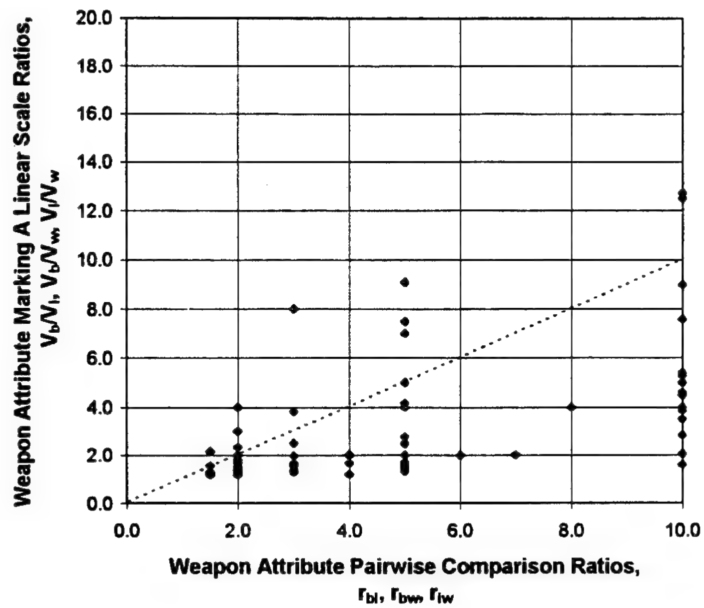



Figure A.D-12

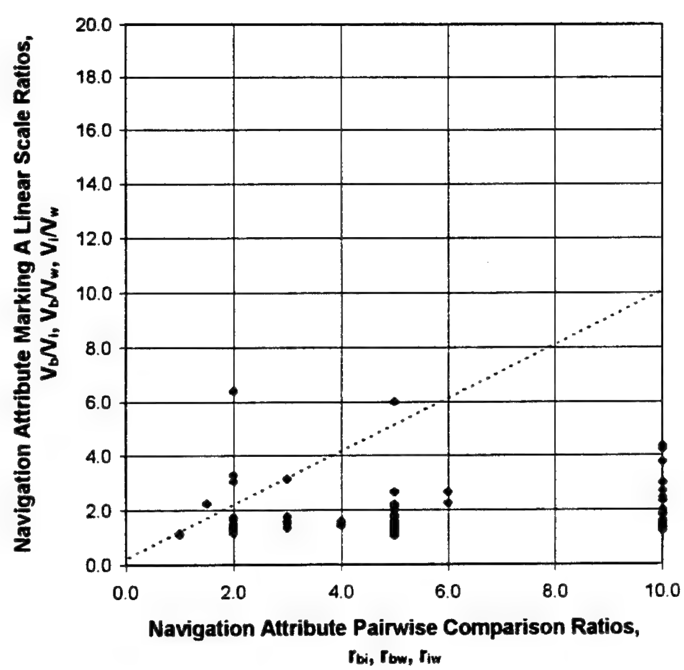



Figure A.D-13

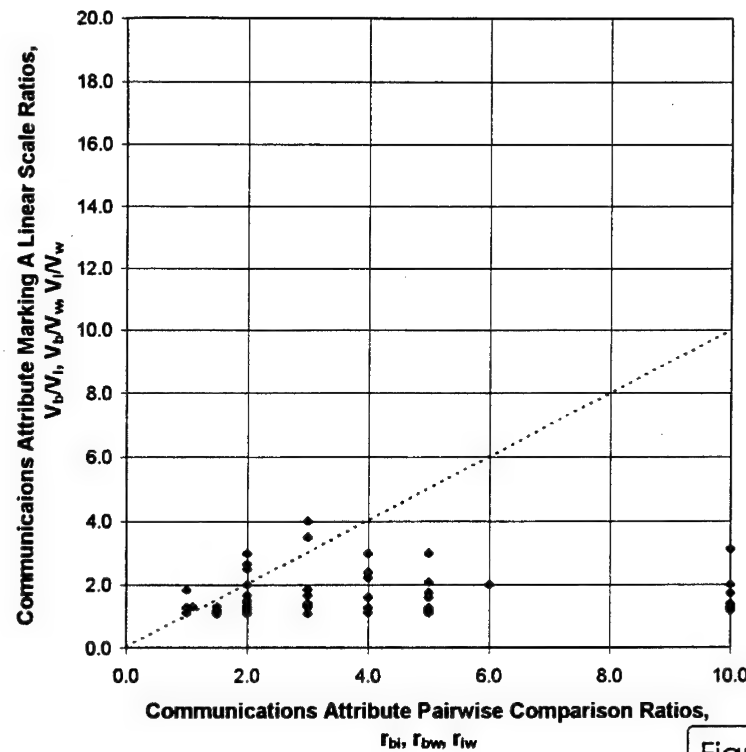



Figure A.D-14

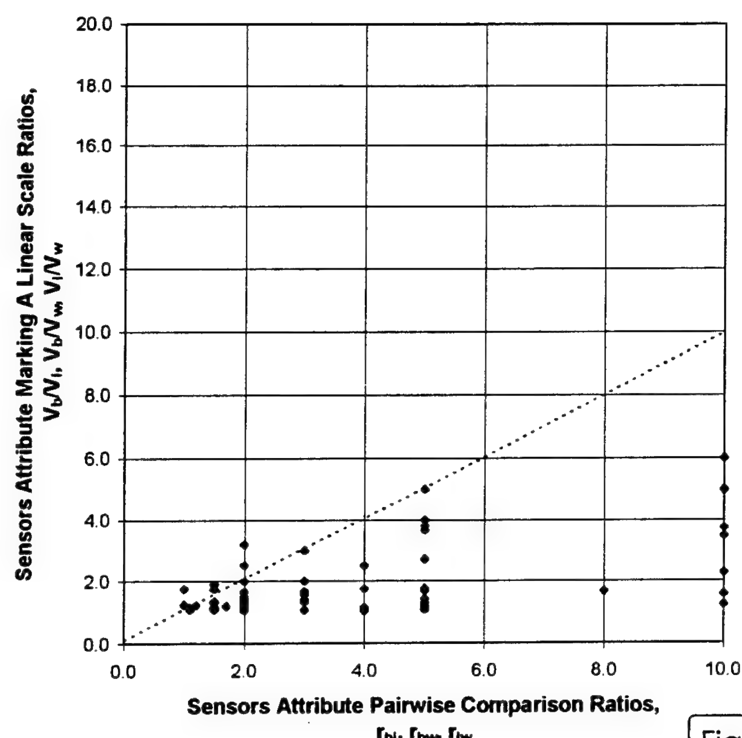
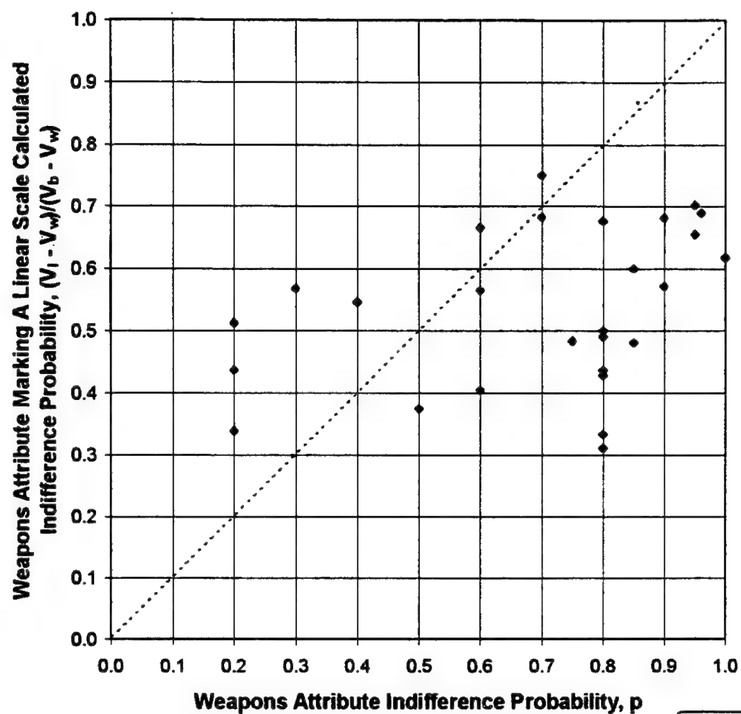



Figure A.D-15

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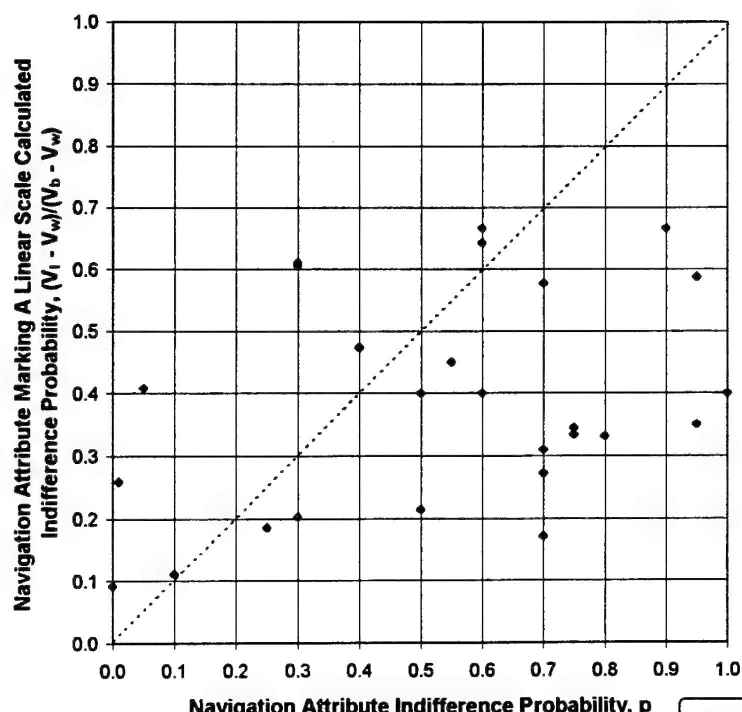


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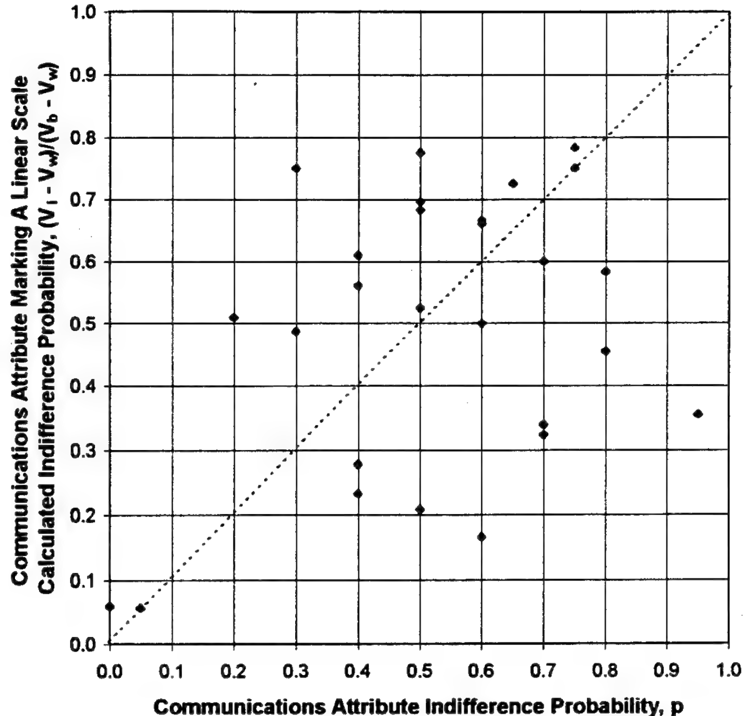


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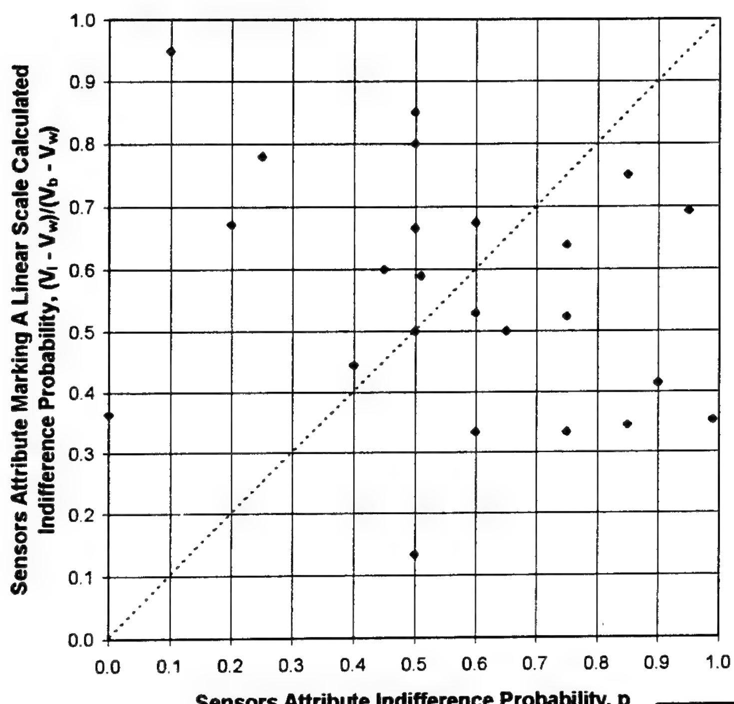


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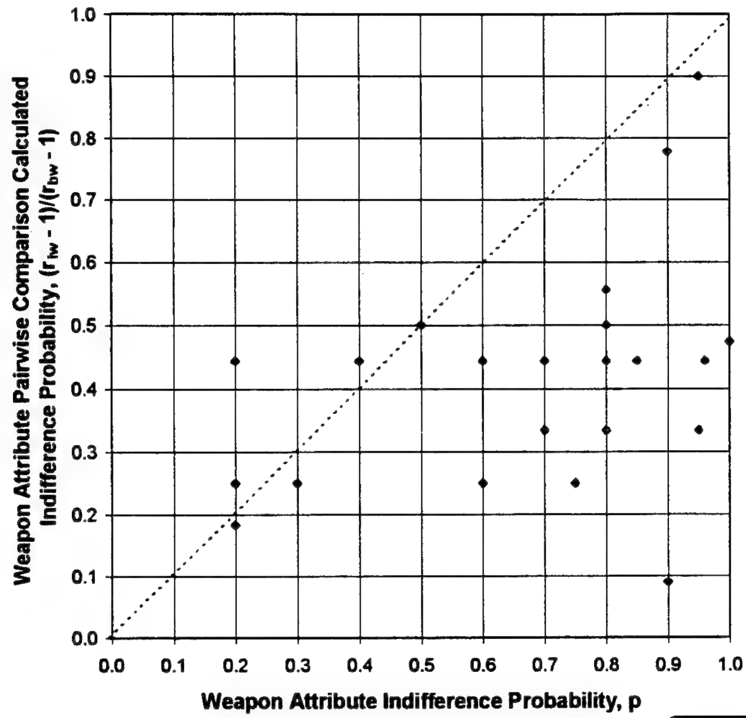


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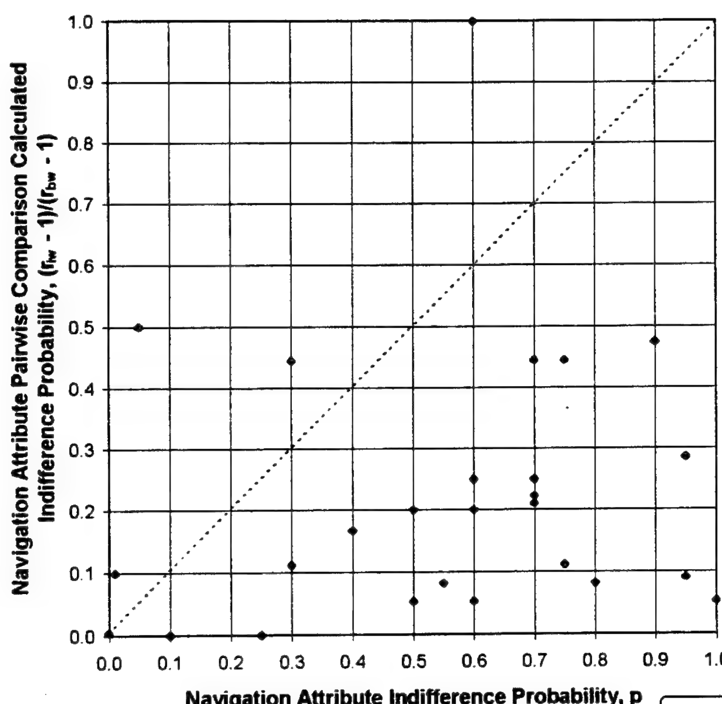


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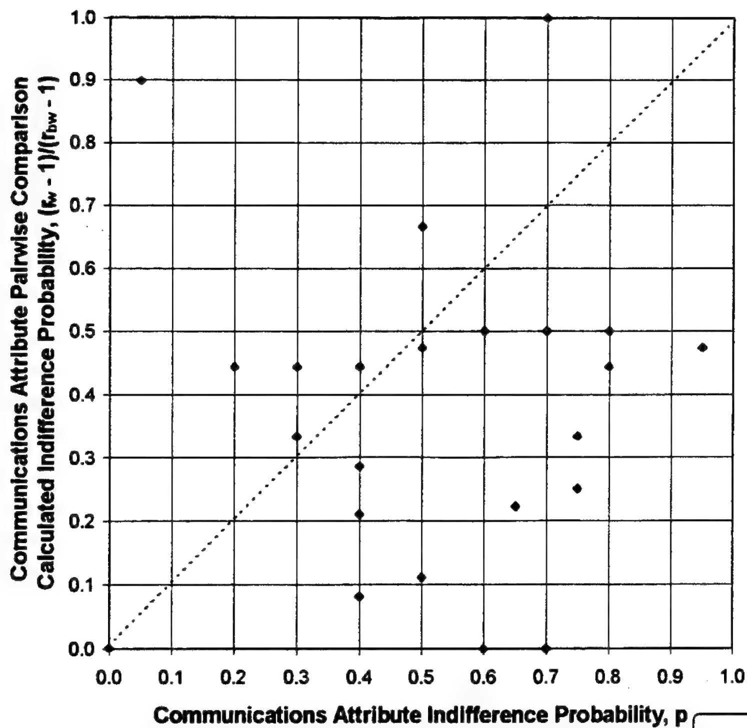


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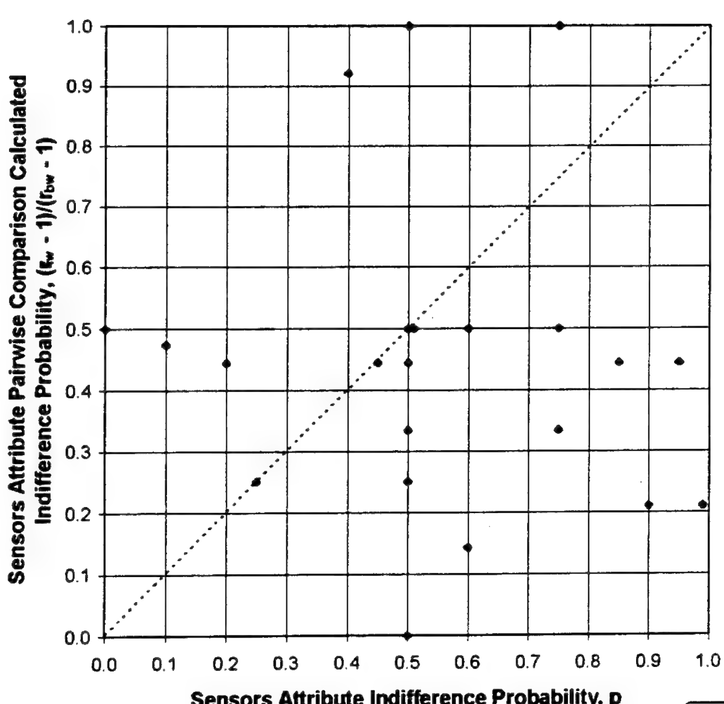


Figure A.D-23

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